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8. Notes/Comments
Interdisciplinary review was not conducted, as it would not impact the results of the calculations or direct citation of the technical outputs by the end users.

Attachments	Total Number of Pages
I. Listing of Computer Files	10
II. One Compact Disc Containing All Files Listed in Attachment I (1 of 1)	0
III. Sketches of DTF and RB and their Moderator Exclusion Areas	8

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. QER (Print/Sign/Date)	16. Approved/Accepted (Print/Sign)	17. Date
00A	Initial issue	68	III-7	C.E. Sanders	G. Radulescu	D.J. Tunney	S. Su	8/14/03
00B	Update and revise the criticality safety evaluation of the DTF and RB. Revision includes new Boral loading for BWR assembly calculations, updated Category 1 and 2 event sequences, and inclusion of Y-12 review comments. Extensive Revision. All pages are affected.	76	~~IV-8~~ III-8	C.E. Sanders SIGNATURE ON FILE 03/02/04	D.S. Kimball SIGNATURE ON FILE 3/2/04	D.J. Tunney SIGNATURE ON FILE 3/2/2004	S. Su SIGNATURE ON FILE	3/2/2004

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LIST OF ACRONYMS AND ABBREVIATIONS

BSC	Bechtel SAIC Company, LLC
BWR	Boiling Water Reactor
CD	Compact Disc
CFR	Code of Federal Regulations
cm	centimeters
CRWMS	Civilian Radioactive Waste Management System
DOE	U.S. Department of Energy
DPC	Dual-Purpose Canister
DTF	Dry Transfer Facility
in	inch
k_{eff}	neutron effective multiplication factor
k_{inf}	neutron infinite multiplication factor
MCNP	Monte Carlo N-Particle transport code
NRC	U.S. Nuclear Regulatory Commission
o.d.	outer diameter
OFA	Optimized Fuel Assembly
PDC	Project Design Criteria
PWR	Pressurized Water Reactor
RB	Remediation Building
s or sec	seconds
SFA	Spent Fuel Assembly
SS	Stainless Steel
SSC	Structures, Systems and Components
SNF	Spent Nuclear Fuel
TD	theoretical density
USL	upper sub-critical limit
WP	Waste Package
wt %	weight percent

1. PURPOSE

The purpose of this design calculation is to revise and update the previous criticality evaluation for the fuel handling, transfer and storage operations to be performed in the Surface Facility documented in BSC 2003c. The scope of this design calculation covers the operations in the Dry Transfer Facility (DTF) and Remediation Building (RB) and their processes as established at the date of this calculation. Also, this design calculation focuses on intact commercial spent nuclear fuel (SNF) assemblies, i.e., pressurized water reactor (PWR) and boiling water reactor (BWR) SNF. A description of the changes is as follows:

- Update the supporting calculations for the various Category 1 and 2 event sequences as identified in the *Preliminary Categorization of Event Sequences for License Application* (BSC 2003a, Section 7).
- Include comments from an informal review conducted by Y-12, located in Oak Ridge, Tennessee (Su 2004).
- Revise the BWR calculations to reflect a different Boral loading.
- Assess effects of potential moderator intrusion into the storage rack area with various water levels for defense in depth based on the new design of the DTF and RB.

As with the superseded document (BSC 2003c), the purpose of this design calculation is still to demonstrate and ensure that the various operations to be performed in the Surface Facility meet the *Project Requirements Document* (Canori and Leitner, p. 3-76) and nuclear criticality safety design criteria as specified in the *Project Design Criteria (PDC) Document* (Minwalla 2003, Section 4.9.2.2). The *Project Functional and Operational Requirements* document (Siddoway 2003) does not provide requirements for this calculation. These operations are referred to as out-of-package operations, consistent with the term used in the *Preclosure Criticality Analysis Process Report* (Scaglione 2003, p. 1).

The DTF and RB have been classified as important to safety in the *Q-list* (BSC 2003b, p. A-2). Further, this calculation provides the criticality safety results to support the design of the DTF and RB. Therefore, this design calculation is subject to the requirements of the *Quality Assurance Requirements and Description* (DOE 2003). Performance of the work scope as described and development of the associated technical product conform to the procedure AP-3.12Q, *Design Calculations and Analyses*.

2. METHOD

2.1 CRITICALITY SAFETY ANALYSIS

The criticality safety calculations presented in this document determine the minimum spacing for PWR and BWR fuel storage racks in the DTF and RB as a function of fuel enrichment (including 5.0 wt %) and moderator density. The poison (Boral) areal density used in this calculation is 0.030 g $^{10}B/cm^2$ for both PWR and BWR SNF storage racks. The process and methodology for criticality safety analysis given in the *Preclosure Criticality Analysis Process Report* (Scaglione 2003, Section 2.1.7) will be implemented in these calculations. For each fuel storage rack configuration, the following method will be followed (Scaglione 2003, Section 2.1.7):

- The design basis for the facilities (i.e., DTF and RB) relies on the most reactive fuel assemblies
- Deterministic evaluations will be used for demonstrating nuclear criticality safety
- Conservative modeling dimensional variables will be used (e.g., assembly pitch, manufacturing tolerances for assemblies etc.) in order to maximize reactivity
- The multiplication factor (k_{eff}) will not exceed 0.95, including all biases and uncertainties in the data and method of the analysis, under all normal, and Category 1 and 2 event sequences
- Conservative modeling assumptions will also be used regarding materials in fuel including no accounting for burnable poisons in fuel, no credit for ^{234}U and ^{236}U in fuel, flooded fuel pin gaps, use of unborated water, and use of the most reactive fuel stack density
- Criticality controls (e.g., grid plates) utilizing neutron absorbing material can only be taken credit for up to 75 % of the neutron absorbing material.

These calculations use the qualified software MCNP (Briesmeister 1997, BSC 2002, and CRWMS M&O 1998). MCNP is a three-dimensional Monte Carlo particle transportation code with the capability to calculate eigenvalues for critical systems. The Nuclear Regulatory Commission (NRC) accepts MCNP in NUREG-1567 (NRC 2000, p. 8-10) for criticality calculations.

The terms “model(s)” and “modeling” as used in this calculation document refer to the geometric configurations of the criticality cases analyzed.

2.2 ELECTRONIC MANAGEMENT OF INFORMATION

Electronic management of information generated from these calculations is controlled in accordance with AP-3.13Q, *Design Control*. The computer input and output files generated from this calculation are stored on a Compact Disc (CD), and submitted as an attachment to this document (Attachment II).

3. ASSUMPTIONS

Assumptions pertaining to the entire document

3.1 The current facility layouts of the DTF and RB and their process designs are used for these calculations. The DTF SNF storage rack consists of a 5 x 5 basket cell array inside a stainless steel (SS) vessel.

Rationale: These facilities (Attachment III) and their process designs are in the preliminary stage of design development. However, the process functions are expected to remain unchanged. It is assumed that design changes to the facility layout will have little or no impact on the criticality results or conclusions presented in this document, as the assumptions used in this design calculation are conservative, and bound possible variations in the design of the DTF and RB.

Usage: This assumption is used throughout this design calculation.

3.2 The RB storage rack configuration is assumed to be the same as the DTF but without the surrounding vessel.

Rationale: A final design has not yet been determined for the storage rack configuration in the RB. Consequently, the RB storage racks were modeled in MCNP utilizing the same dimensions and fuel array configuration as in the DTF. The only difference between the DTF and RB MCNP input is that the RB input does not contain an outside vessel, which is a conservative assumption.

Usage: This assumption is used throughout this design calculation.

3.3 The nominal acceptable calculated value of k_{eff} is assumed to be 0.925 as a criticality limit in order to meet the design criteria specified in the PDC Document [i.e., k_{eff} can not exceed 0.95 including uncertainties and bias at 95% confidence level (Minwalla 2003, Section 4.9.2.2.1)]. In other words, the nominal value provides a margin of 0.025 (0.95 - 0.925) to account for code bias and uncertainties at 95% confidence level.

Rationale: Uncertainties and bias that need to be considered in this analysis pertain to statistical uncertainties, dimensional uncertainties, code bias, and tolerance uncertainties. Applicable code bias for the fuel type and enrichment range of this analysis is typically less than 0.5 % (CRWMS M&O 1999, Section 4). An allowance of 2% is provided to account for the remaining uncertainties associated with statistical variation, dimensional variables and tolerances. This allowance is similar to, and slightly greater than (conservative), the value used for the SNF storage and transportation cask criticality evaluations (General Atomics 1993a, p. 6.4-7). The fuel storage racks used in the DTF and RB are similar in design to the fuel baskets used in the NRC-certified SNF storage and transportation casks.

Usage: This assumption is used throughout this design calculation.

3.4 The DTF and RB storage racks are assumed to always be full.

Rationale: In reality, the storage racks may not always be full. However, for modeling purposes this is a bounding and conservative assumption.

Usage: This assumption is used throughout this design calculation.

3.5 The fuel stack density was assumed to be 96 % theoretical density (TD).

Rationale: This fuel density is consistent with the value typically used in the safety analysis report for the storage and transportation cask systems (e.g., HI-STAR 100 system (Holtec International 1996)). This value was considered conservative (more reactive), according to the citation on p. 6.1-2 of the *Topical Safety Analysis Report for the Holtec International Storage, Transport and Repository Cask System (HI-STAR 100 Cask System)*.

Usage: This assumption is used throughout this design calculation.

<u>Assumptions Relating to Pin Cell Calculation</u>

3.6 When determining the most reactive PWR and BWR fuel (Scaglione 2003, Section 2.1.7), a simplified pin cell MCNP input was assumed, in addition to a full assembly MCNP input, to save on calculation time.

Rationale: The pin cell models represent the fuel rod array in a fuel assembly. The pin cell models exclude the water holes in each fuel assembly, and simplify the computer input considerably. Without the water holes, the pin cell models are less conservative than the explicit fuel assembly model. However, the purpose of the pin cell calculation is to demonstrate that the simplified models produce the same conclusion as the explicit full fuel assembly geometry with respect to the most reactive fuel assembly. Further, the pin cell models are not intended to provide absolute k_{eff} values. When the pin cell calculations show any contradictory results, the explicit full assembly geometry is used to verify the most reactive fuel type.

Usage: This assumption is used in Section 5.1.

<u>Storage Rack Calculations</u>

3.7 The MCNP models include axial reflection by modeling a water region above and below the active fuel with an assumed height of 30 cm. The plenum region and end fittings are not included in the model.

Rationale: The specified water thickness simulates infinite water reflection. The actual structure of the fuel assembly and storage racks will provide reduced reflection due to axial leakage via the fuel pin plenums and neutron absorption in the fuel assembly end fittings and the rack structure.

Usage: This assumption is used in Section 5.1.

3.8 The MCNP models of the PWR and BWR fuel storage racks include the sections of the racks containing the active fuel region.

Rationale: This is a conservative and simplifying model assumption. The calculated eigenvalue of the system model increases by excluding those materials beyond the active fuel region and replacing them with water (General Atomics 1993b, p. 6.4-1).

Usage: This assumption is used in Section 5.1.

3.9 The fuel basket cell for the storage rack includes a small water channel between the Boral panel and stainless steel (SS) support wall.

Rationale: The fuel basket cell dimensions and Boral panel specifications indicate that there is a small gap between the Boral panel and the cell SS wall (Wagner and Parks 2000, p. 7). There is no mechanism to prevent this small gap to be filled with water for flooded conditions. Consequently, the MCNP models feature a small water channel between the Boral panel and SS support wall

Usage: This assumption is used in Section 5.1.

3.10 The BWR cell basket configuration was assumed to consist of a 9 x 9 array, based on a 5 x 5 array for the PWR fuel storage racks.

Rationale: Due to the fact that the BWR fuel assemblies are smaller than the PWR fuel assemblies, more cell basket can fit inside the same area as the PWR fuel assemblies. Based on the BWR fuel assembly dimensions, a 9 x 9 BWR configuration was found to be equivalent in terms of physical space available to the 5 x 5 array for the PWR fuel storage racks.

Usage: This assumption is used in Section 5.1.

3.11 The PWR and BWR cell basket thicknesses and materials were assumed to be identical.

Rationale: Since the BWR fuel featured the same characteristics as the PWR (e.g., fresh fuel assumption, enrichment range), the equivalent poison loading and material thicknesses are appropriate for the basket configuration.

Usage: This assumption is used in Section 5.1.

4. USE OF COMPUTER SOFTWARE

4.1 BASELINED SOFTWARE

4.1.1 MCNP

The MCNP code (CRWMS M&O 1998 and BSC 2002) was used to calculate the multiplication factor, k_{eff}, for all systems presented in this report (i.e., PWR and BWR pincell configurations, and PWR and BWR fuel storage rack configurations). The software specifications are as follows:

- Program Name: MCNP (CRWMS M&O 1998 and BSC 2002)
- Version/Revision Number: Version 4B2LV
- Status/Operating System: Qualified/HP-UX B.10.20 and Qualified/Windows 2000
- Software Tracking Number: 30033 V4B2LV and 10437-4B2LV-00
- Computer Type: HP 9000 Series Workstations and Personal Computer
- CPU Number: 700887 and 151718

The input and output files for the various MCNP calculations are contained on a CD (Attachment II) and the files are listed in Attachment I.

The MCNP software used was: (1) appropriate for the criticality (k_{eff}) calculations, (2) used only within the range of validation, and (3) obtained from Software Configuration Management in accordance with appropriate procedures.

4.2 COMMERCIAL OFF-THE-SHELF SOFTWARE

4.2.1 MICROSOFT EXCEL 97 SR-2

- Title: Excel
- Version/Revision Number: Microsoft® Excel 97 SR-2
- This version is installed on a PC running Microsoft Windows 2000 with CPU number 151718

The files for the various Excel calculations are contained on a CD (Attachment II) and the files are listed in Attachment I.

The Excel software was used to calculate weight percent of each component (i.e., ^{235}U, ^{238}U and O) in fresh UO_2 as a function of initial enrichment, and to illustrate the results in Section 6. The calculations performed with Excel can be reproduced and checked by hand. Excel is exempt from qualification per Section 2.1.6 of AP-SI.1Q, *Software Management*.

5. CALCULATION

All technical product inputs and sources of the inputs used in the development of this calculation are documented in this section.

5.1 CALCULATIONAL INPUTS

5.1.1 Design Requirements and Criteria

The design criteria for criticality safety analysis provided in Section 4.9.2.2 of the *Project Design Criteria* document (Minwalla 2003) are used in these calculations. The pertinent criteria for surface facility criticality include the following (Minwalla 2003, Section 4.9.2.2):

- The multiplication factor (k_{eff}) will not exceed 0.95, including all biases and uncertainties in the data and method of the analysis, under all normal and off-normal event sequences. This criterion satisfies Requirement Number PRD-013/T-022 in the *Project Requirements Document* (Canori and Leitner 2003, p. 3-76).

- The facility design will utilize a favorable geometry and/or fixed neutron absorbers without the use of burnup credit.

- No moderator shall be present in any area where radioactive waste is being handled (cask unloading, storage areas etc.) unless the facility design (such as a SNF storage pool) or proposed quantity of moderator material can be shown to impose no criticality concerns. Attachment III features sketches of the DTF and RB as of the date of this calculation, and may not reflect the ongoing design evolution. The purpose of the sketches is to show functional areas where moderator exclusion is engineered in the design for criticality safety. These functional areas will remain with moderator exclusion, even if design changes are made to the DTF or RB with respect to the layout.

5.1.2 Pin Cell Calculation

In accordance with the requirements given in *Preclosure Criticality Analysis Process Report* (Scaglione 2003, Section 2.1.7), the design of the storage fuel racks should be based on most reactive fuel assemblies. An evaluation was performed with MCNP for PWR and BWR fuel to determine the most reactive fuel assembly. Per Assumption 3.6, the calculations utilized a simplified pin cell model where only one fuel pin was modeled, in addition to modeling the entire fuel assemblies, to save on computer time.

5.1.2.1 Pin Cell Selections and Physical Dimensions

Table 5.1-1 lists the PWR and BWR fuel assemblies considered and their fuel parameters. Figure 5.1-1 displays a cross-sectional view of the pin cell model used for this analysis.

Table 5.1-1 Fuel Types Evaluated and their Fuel Parameters

Manufacturer	Array and Version	Pin pitch [a] (cm)	Clad o.d. [a] (cm)	Clad thickness [b] (cm)	Pellet diameter [a] (cm)	U-235 wt % enrichment [b, e]
PWR fuel assemblies						
Westinghouse	17x17 STD	1.25984	0.94996	0.05715	0.81915	3.80, 5.00
Westinghouse	17x17 OFA	1.25984	0.91440	0.05715	0.784352	3.80, 5.00
Westinghouse	17x17 Vantage 5H	1.25984	0.91440	0.05715	0.784352	3.80, 5.00
Westinghouse	15x15 Std/ZC	1.43002	1.07188	0.061468	0.929386	3.80, 5.00
Westinghouse	15x15 OFA	1.43002	1.07188	0.061468	0.929386	3.60, 5.00
Westinghouse	14x14 Std/ZCA	1.41224	1.07188	0.05715	0.933196	3.40, 5.00
Westinghouse	14x14 Std/ZCB	1.41224	1.07188	0.05715	0.933196	3.40, 5.00
Westinghouse	14x14 Model C	1.4732	1.1176	0.06604	0.966470	3.30, 5.00
Westinghouse	14x14 OFA	1.41224	1.016	0.06172	0.874776	3.60, 5.00
B&W	17x17 Mark C	1.27508	0.96266	0.06096	0.820928	3.00, 5.00
B&W	Mark B, BZ, BGD	1.44272	1.0922	0.06731	0.936244	3.00, 5.00
CE	16x16 St. Lucie	1.28524	0.97028	0.06350	0.82550	3.66, 5.00
CE	15x15 Palisades	1.3970	1.06172	0.06604	0.90932	2.90, 5.00
CE	14x14Std/Gen	1.4732	1.1176	0.07102	0.95631	4.05, 5.00
CE	14x14 Ft. Calhoun	1.4732	1.1176	0.07102	0.95631	3.80, 5.00
BWR fuel assemblies						
Manufacturer	Array and Version	Pin pitch [c] (cm)	Clad o.d. [c] (cm)	Clad thickness [d] (cm)	Pellet diameter [c] (cm)	U-235 wt % enrichment [e]
GE	7x7 Std	1.87452	1.43002	0.08128	1.23698	4.50, 5.00
GE	8x8 Std	1.62814	1.25222	0.08636	1.05664	4.50, 5.00

[a] Source: General Atomics 1993a, p 6.2-2
[b] Source: DOE 1987, p. 2A-289, 2A-291, 2A-295, 2A-297, 2A-301, 2A-303, 2A-313, 2A-315, 2A-319, 2A-321, 2A-325, 2A-327, 2A-343, 2A-345, 2A-349, 2A-351, 2A-355, 2A-357, 2A-31, 2A-33, 2A-49, 2A-51, 2A-55, 2A-57, 2A-61, 2A-63, 2A-67, 2A-69, 2A-79, and 2A-81
[c] Source: General Atomics 1993b, p 6.2-2
[d] Source: DOE 1992, p. 2A-15 and 2A-16
[e] Fuel enrichments used in calculations

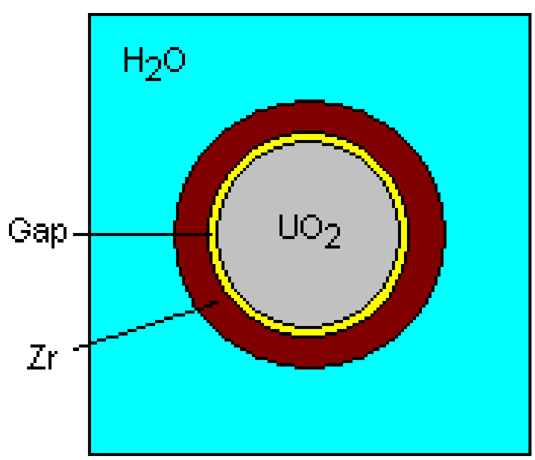

Figure 5.1-1 Cross-section View of Pin Cell Model

5.1.2.2 Pin Cell Material Compositions

The calculations for the most reactive fuel analysis were performed with either the isotopic composition given in weight percents (wt %) or atom fractions, depending on the source of the input. Table 5.1-2 displays the relevant material properties used for the PWR and BWR pin cell models.

Table 5.1-2 Material Properties for the Pin Cell Cases

Material	Density (g/cm^3)	Element	Weight Percent (wt %) [b]	Atom Fraction	Reference
H_2O	1.0	H O	N/A	0.66667 0.33333	General Atomics 1993a, p. 6.4-3
Zirconium	6.44	Zr	N/A	1	General Atomics 1993b, p. 6.3-4
UO_2 – 2.90 % enriched	10.5216 [a]	U-235 U-238 O-16	2.5563 85.5935 11.8502	N/A	-----------
UO_2 – 3.00 % enriched	10.5216	U-235 U-238 O-16	2.6445 85.5053 11.8502	N/A	-----------
UO_2 – 3.30 % enriched	10.5216	U-235 U-238 O-16	2.9089 85.2409 11.8502	N/A	-----------
UO_2 – 3.40 % enriched	10.5216	U-235 U-238 O-16	2.9971 85.1527 11.8502	N/A	-----------
UO_2 – 3.60 % enriched	10.5216	U-235 U-238 O-16	3.1734 84.9764 11.8502	N/A	-----------
UO_2 – 3.66 % enriched	10.5216	U-235 U-238 O-16	3.2263 84.9235 11.8502	N/A	-----------
UO_2 – 3.80 % enriched	10.5216	U-235 U-238 O-16	3.3497 84.8001 11.8502	N/A	-----------
UO_2 – 4.05 % enriched	10.5216	U-235 U-238 O-16	3.5701 84.5797 11.8502	N/A	-----------
UO_2 – 4.50 % enriched	10.5216	U-235 U-238 O-16	3.9667 84.1831 11.8502	N/A	-----------
UO_2 – 5.00 % enriched	10.5216	U-235 U-238 O-16	4.4075 83.7423 11.8502	N/A	-----------

[a] Assumption 3.5. UO_2 theoretical density is 10.96 g/cm^3 (CRWMS M&O 2000, p. M8.2.27)
[b] Calculations can be found in Excel file *fuelcomp.xls* (source for the atomic weight: Parrington et. al., 1996).

5.1.3 Storage Rack Calculation Inputs

The storage racks in the DTF and RB were modeled as they are currently designed in accordance with Attachment III (Assumption 3.1). Physical inputs for the storage racks are described in the following subsections.

5.1.3.1 DTF PWR Storage Rack Configuration and Physical Dimensions

The storage rack configuration for the DTF PWR fuel assemblies consists of a 5 x 5 basket cell array inside a 2 m, in diameter (approximately), SS vessel (Assumption 3.1). Figure 5.1-2 displays the 5 x 5 cell array inside the vessel. For conservatism in criticality safety analysis, the MCNP models of the fuel storage racks only include the sections of the racks containing the active fuel region (Assumption 3.8). Further, the vessel containing the 5 x 5 basket cell array was modeled as full (Assumption 3.4). The model also includes axial reflection by modeling a 30 cm water region above and below the active fuel region (Assumption 3.7). Figure 5.1-3 shows an axial view of the storage rack inside the vessel.

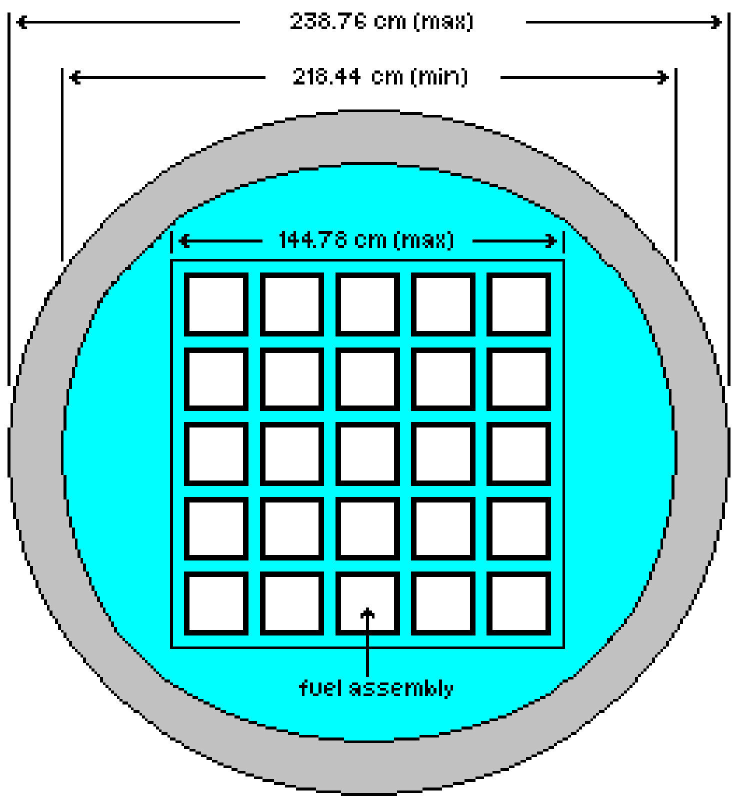

Figure 5.1-2 Radial View of the 5 x 5 PWR Fuel Storage Cell Array Inside Vessel
(Source: Assumption 3.1)

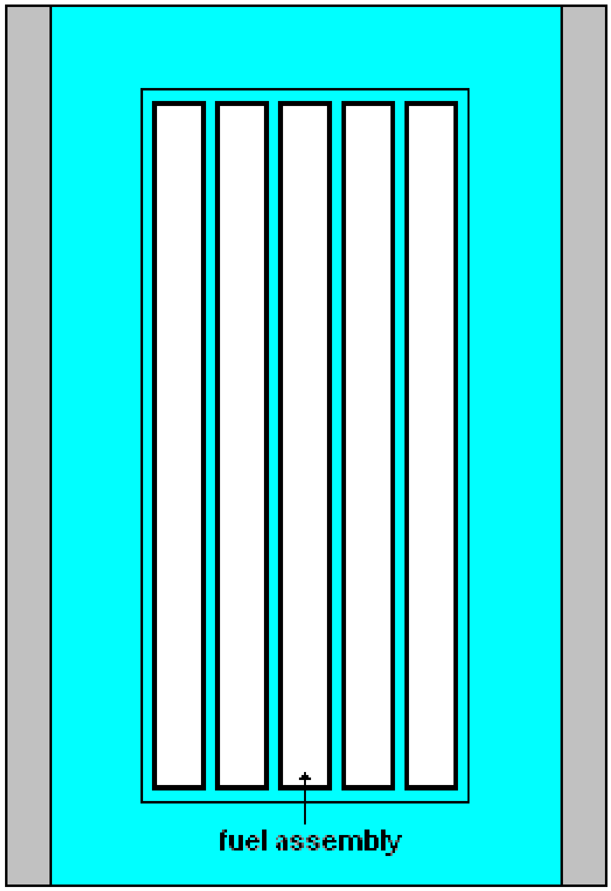

Figure 5.1-3 Axial View of the 5 x 5 PWR Fuel Storage Rack Inside Vessel
(Source: Assumption 3.1)

The PWR storage rack basket cells were modeled featuring SS walls with a Boral panel situated on each side (Wagner and Parks 2000, p. 8). In the MCNP model, the Boral panel, which contains a ^{10}B loading of 0.030 g $^{10}B/cm^2$ (Wagner and Parks 2000, p. 7), is assumed to rest in a water channel (Assumption 3.9). The ^{10}B loading is similar to the value (0.0276 g $^{10}B/cm^2$) used in the HI-STAR 100 cask system (Holtec International 1996, p. 6.3-4). The Boral thickness, T, can be calculated from the expression:

$$T = \frac{M}{S_a} \times \frac{N_A}{M_a} \times \frac{1}{A} \qquad \text{(equation 1)}$$

where

M = weight (g)
S_a = surface area (Boral areal density is 0.0276 g $^{10}B/cm^2$ (Holtec International 1996, p. 6.3-4))
N_A = Avogadro's constant (6.023E+23 atoms/mole (Parrington et. al. 1996))
M_a = ^{10}B atomic weight (10.0129371 g/mole (Parrington et. al. 1996))
A = ^{10}B atom density (8.0707E-03 atoms/cm·barn (Holtec International 1996, p. 6.3-4))

It should also be mentioned that equation 1 is derived from the definition of atom density, A, as described below:

$$A = \frac{N_a}{V} = \frac{N_m \times N_A}{V} = \frac{M}{M_a} \times \frac{N_A}{V} = \frac{M}{S_a \times T} \times \frac{N_A}{M_a} \qquad \text{(equation 2)}$$

where

N_a = number of atoms
N_m = number of moles
V = volume
T = thickness (cm)

Solving equation 1 gives a Boral thickness, T, of 0.2057 cm.

The storage rack basket cells contains a Westinghouse 17 x 17 Optimized Fuel Assembly (OFA) assembly, since it is the most reactive PWR fuel (Section 5.2.1). Figure 5.1-4 displays the storage rack basket cell with the Westinghouse 17 x 17 OFA and Table 5.1-3 features the dimensions of the storage rack and cell geometry, and Table 5.1-4 displays the fuel specifications.

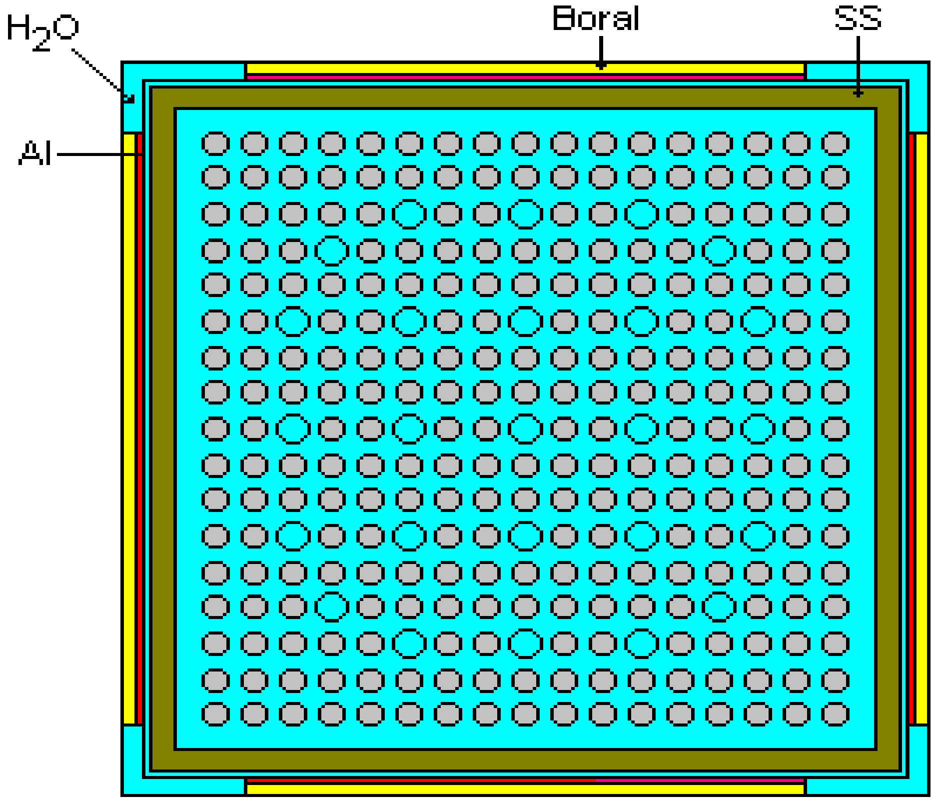

Figure 5.1-4 PWR Storage Rack Basket Cell Containing W 17 x 17 OFA
(Source: Wagner and Parks 2000, p. 8)

Table 5.1-3 Dimensions of the Storage Rack and Cell Geometry

Component	Dimension (cm)	Reference
Outside Vessel Diameter	238.76	Assumption 3.1
Inside Vessel Diameter	218.44	Assumption 3.1
Storage Rack ‘Box’	144.78	Assumption 3.1
Cell inside dimension	22.225	Wagner and Parks 2000, p.7
Cell pitch	22.784	Wagner and Parks 2000, p.7
Cell wall thickness	0.1905	Wagner and Parks 2000, p.7
Boral panel thickness	0.2564	Wagner and Parks 2000, p.7
Boral thickness	0.2057	Calculated in Section 5.1.3.1
Al thickness	0.0254	Boral panel thickness – Boral thickness – water channel thickness
Boral width	19.05	Wagner and Parks 2000, p.7
Water channel thickness	0.02286	Assumption 3.9

Table 5.1-4 Specifications of the PWR W 17 x17 OFA

Parameter	Dimension (cm)	Reference
Rod pitch	1.260	Sanders and Wagner 2002, p.8
Rod length	365.76	DOE 1987, p.2A-351
Cladding outside diameter	0.9144	General Atomics 1993a, p.6.2-2
Cladding inside diameter	0.8002	DOE 1987, p.2A-351
Pellet outside diameter	0.784352	General Atomics 1993a, p.6.2-2
Guide/instrument tube outside diameter	1.204	Sanders and Wagner 2002, p.8
Guide/instrument tube inside diameter	1.124	Sanders and Wagner 2002, p.8
Array size	17 x 17	Sanders and Wagner 2002, p.8
Number of fuel rods	264	Sanders and Wagner 2002, p.8
Number of guide/instrument tubes	25	Sanders and Wagner 2002, p.8

5.1.3.2 PWR Material Compositions

The calculations were performed with either the isotopic compositions given in weight density (wt%) or atom densities (atoms/barn-cm), depending on the source of the input. Table 5.1-5 displays the relevant materials used for the storage rack and the PWR fuel.

Table 5.1-5 Material Properties for the Storage Rack and PWR Fuel

Material	**Density (g/cm^3)**	**Element**	**Weight Percent (wt %)**	**Atom Fraction or Atom Density (atoms/barn-cm)**	**Reference/ Remark**
H_2O (throughout model)	1.0 [a]	H O	N/A	Fraction - 0.66667 Fraction - 0.33333	General Atomics 1993b, p. 6.4-3
SS304 (vessel & cell wall)	7.92	Cr Mn Fe Ni	19.0 2.0 69.5 9.5	N/A	General Atomics 1993a, p.6.3-4
Al (Boral panel)	----	Al	N/A	0.0602 [c]	-----------
Boral	-----	Al B-10 B-11 C	N/A	3.55590E-02 6.57945E-03 3.84015E-02 1.12730E-02	Elemental atom densities are calculated values, based on a B-10 loading of 0.03 g/cm^2 with 75% credit, and a Boral plate thickness of 0.2057 cm (Table 5.1-3). The remaining 25% B-10 is replaced with B-11 to conserve the Boral mass.
UO_2 – (fuel) 4.00 % enriched	10.5216 [b]	U-235 U-238 O-16	3.5260 [c] 84.6238 [c] 11.8502 [c]	N/A	-----------
UO_2 – (fuel) 4.50 % enriched	10.5216 [b]	U-235 U-238 O-16	3.9667 [c] 84.1831 [c] 11.8502 [c]	N/A	-----------
UO_2 – (fuel) 5.00 % enriched	10.5216 [b]	U-235 U-238 O-16	4.4075 [c] 83.7423 [c] 11.8502 [c]	N/A	-----------
Zr (Cladding)	6.44	Zr	100	N/A	General Atomics 1993a, p.6.3-4

[a] The moderator density was varied between 0.0 – 1.0 g/cm^3 to study moderator density variations in Section 6
[b] Assumption 3.5
[c] Calculations can be found in Excel file *fuelcomp.xls* (source for the atomic weight: Parrington et. al., 1996)

5.1.3.3 DTF BWR Storage Rack Configuration and Physical Dimensions

The storage rack configuration for the DTF BWR fuel assemblies consists of a 9 x 9 basket cell array (Assumption 3.10) inside a 2 m, in diameter (approximately), SS vessel (Assumption 3.1 and Assumption 3.10). Figure 5.1-5 displays the 9 x 9 basket cell array inside vessel. Like in the PWR storage rack calculation, the MCNP model of the fuel storage racks only include the sections of the racks containing the active fuel region (Assumption 3.8) and the vessel containing the 9 x 9 basket cell array was modeled full (Assumption 3.4). Also, the model includes axial reflection by modeling a 30 cm water region above and below the active fuel region (Assumption 3.7). Figure 5.1-6 shows an axial view of the storage rack inside the vessel.

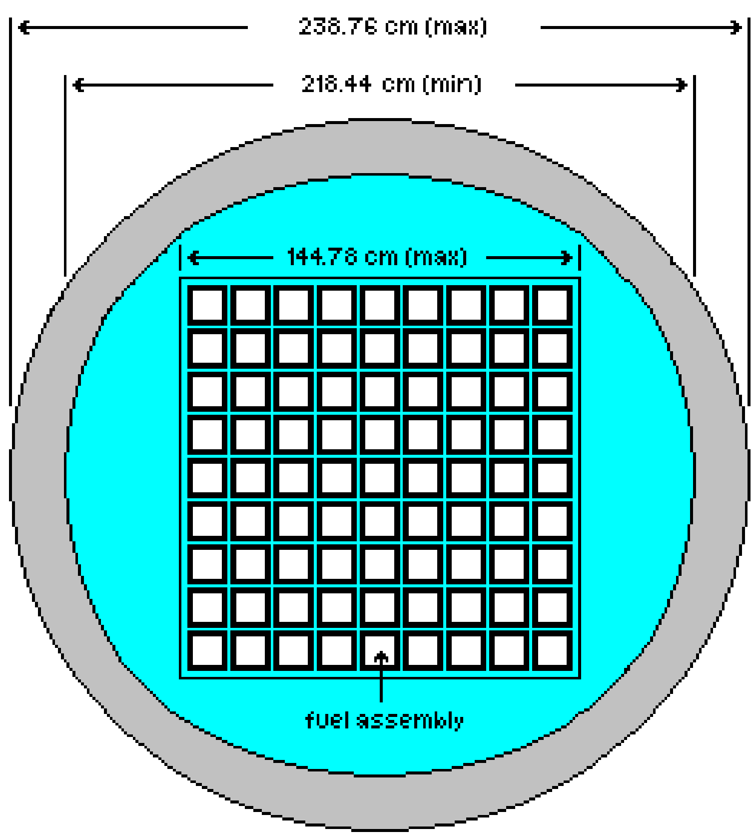

Figure 5.1-5 Radial View of the 9 x 9 BWR Fuel Storage Cell Array Inside Vessel
(Source: Assumption 3.10)

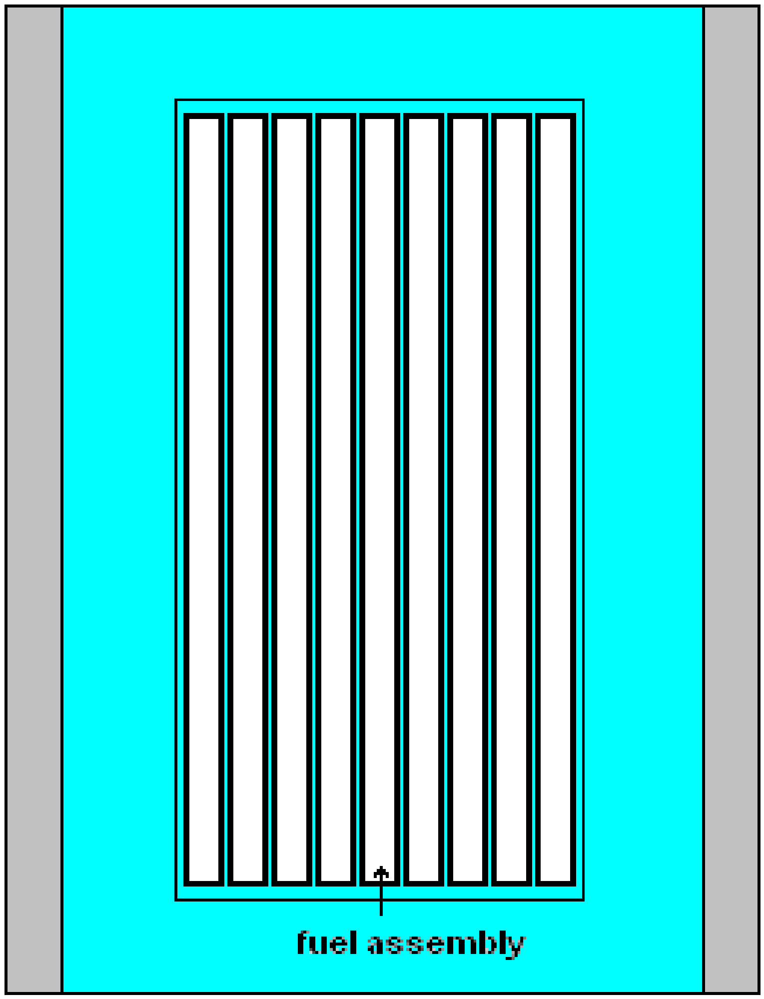

Figure 5.1-6 Axial View of the 9 x 9 BWR Fuel Storage Rack Inside Vessel
(Source: Assumption 3.10)

The BWR storage rack basket cells were assumed to feature the same materials and thicknesses as the PWR basket cells (Assumption 3.11). The ^{10}B loading in Boral is 0.030 g $^{10}B/cm^2$ (Wagner and Parks 2000, p. 7) and is resting in a water channel (Assumption 3.9). The storage rack basket cells contains a GE 7 x 7 Standard assembly, since it is the most reactive BWR fuel (Section 5.2.1). Figure 5.1-7 displays the storage rack basket cell with the GE 7 x 7 Standard assembly. Table 5.1-6 features the dimensions of the storage rack and cell geometry, and Table 5.1-7 displays the fuel specifications.

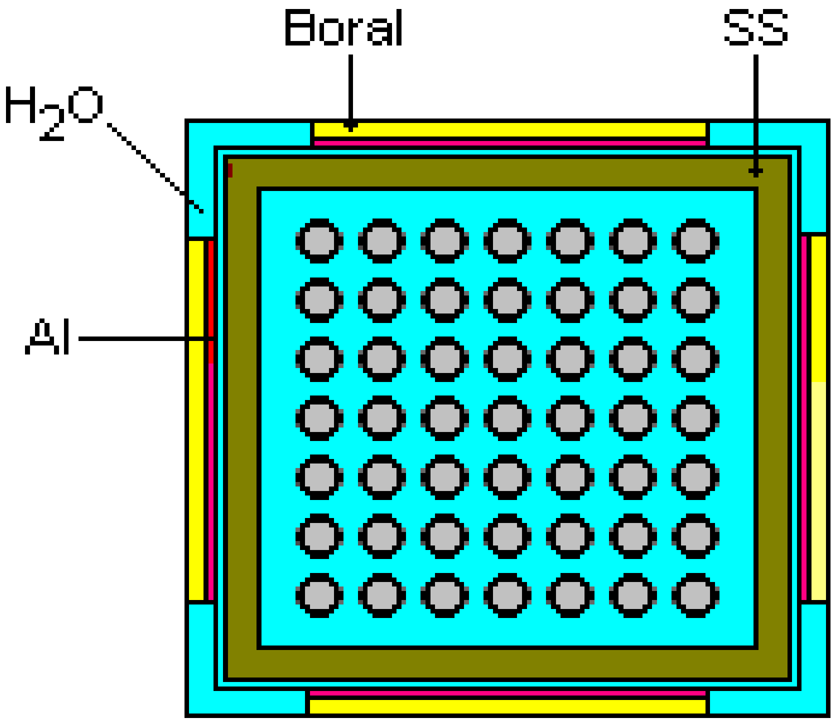

Figure 5.1-7 BWR Storage Rack Basket Cell Containing GE 7 x 7 Standard Assembly
(Source: Wagner and Parks 2000, p. 8)

Table 5.1-6 Dimensions of the BWR Storage Cell Geometry

Component	Dimension (cm)	Reference
Outside Vessel Diameter	238.76	Assumption 3.1
Inside Vessel Diameter	218.44	Assumption 3.1
Storage Rack 'Box'	144.78	Assumption 3.1
Cell pitch	13.81252	DOE 1992, p. 2A-15
Cell wall thickness	0.1905	Wagner and Parks 2000, p.7
Boral panel thickness	0.2564	Wagner and Parks 2000, p.7
Boral thickness	0.20574	Calculated in Section 5.1.3.1
Al thickness	0.0254	Boral panel thickness – Boral thickness – water channel thickness
Boral width	11.43	Reduced by approximately the same factor as the PWR-to-BWR cell pitch ratio (Table 5.1.3)
Water channel thickness	0.02286	Assumption 3.9

Table 5.1-7 Specifications of the BWR GE 7 x 7 Standard Assembly

Parameter	Dimension (cm)	Reference
Rod pitch	1.87452	General Atomics 1993b, p.6.2-2
Rod length	365.76	DOE 1992, p. 2A-15
Cladding outside diameter	1.4300	General Atomics 1993b, p.6.2-2
Cladding inside diameter	1.26746	DOE 1992, p. 2A-15
Pellet outside diameter	1.23698	General Atomics 1993b, p.6.2-2
Array size	7 x 7	General Atomics 1993b, p. 6.2-2
Number of fuel rods	49	DOE 1992, p. 2A-15
Number of guide/instrument tubes	0	DOE 1992, p. 2A-15

5.1.3.4 BWR Material Compositions

The BWR material compositions are identical to those of the PWR material specifications. Therefore, Table 5.1-5 that displays the relevant materials used for the storage rack and the PWR fuel is also applicable to the BWR calculations.

5.1.4 RB Storage Racks

Per Assumption 3.2, the storage rack configuration for the RB is assumed to consist of a 5 x 5 array for the PWR fuel assemblies and a 9 x 9 array for the BWR fuel assemblies. This is the same configuration as for the DTF storage rack but without the surrounding SS vessel. The dimensions of the PWR storage rack and PWR fuel assembly can be found in Tables 5.1-3 and 5.1-4, respectively. The dimensions of the BWR storage rack and BWR fuel assembly can be found in Tables 5.1-6 and 5.1-7, respectively. The material properties are the same as in Table 5.1-5. Figure 5.1-8 displays the configurations of the PWR and BWR storage racks.

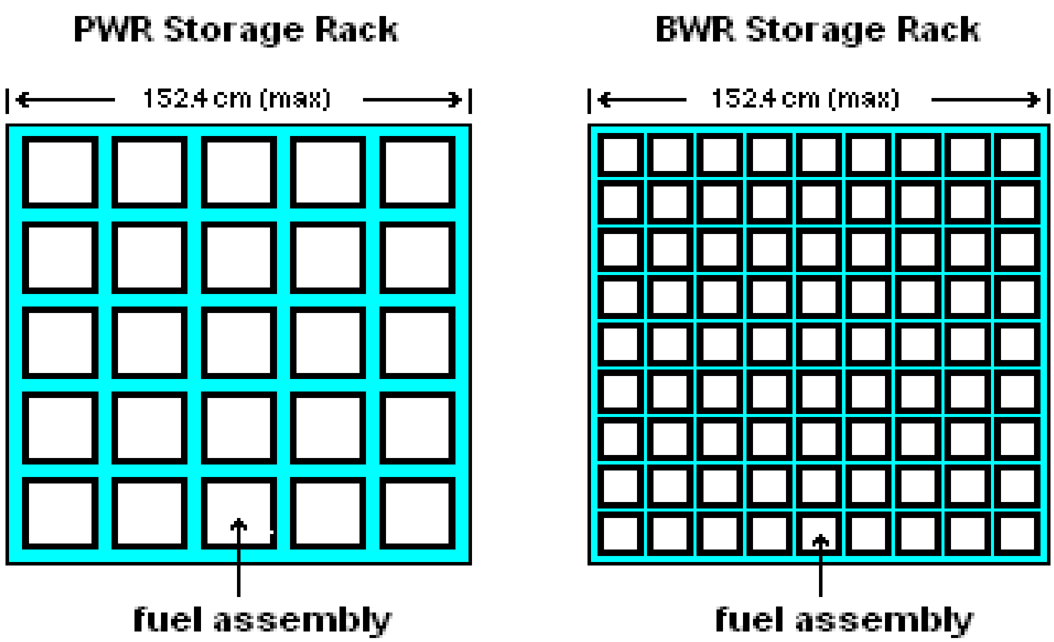

Figure 5.1-8 PWR and BWR Storage Rack Configuration
(Source: Assumption 3.2)

5.1.5 Category 1 and 2 Event Sequences

The DTF PWR storage rack configuration described in Section 5.1.3.1 and BWR storage rack configuration described in Section 5.1.3.3 were used for the MCNP Category 1 and Category 2 evaluations, including their material compositions (Table 5.1-5). Criticality evaluations were performed for double fuel stacking configurations for both the DTF PWR and BWR storage racks. Figure 5.1-9 displays the vertical double fuel stacking configuration for the BWR storage rack (same principle for the PWR fuel storage rack) where one fuel assembly is stacked on top of a full storage rack. In addition, criticality evaluations were performed for a horizontal double fuel stacking configuration for the RB PWR storage rack. Figure 5.1-10 displays the horizontal double fuel stacking configuration for the PWR storage rack.

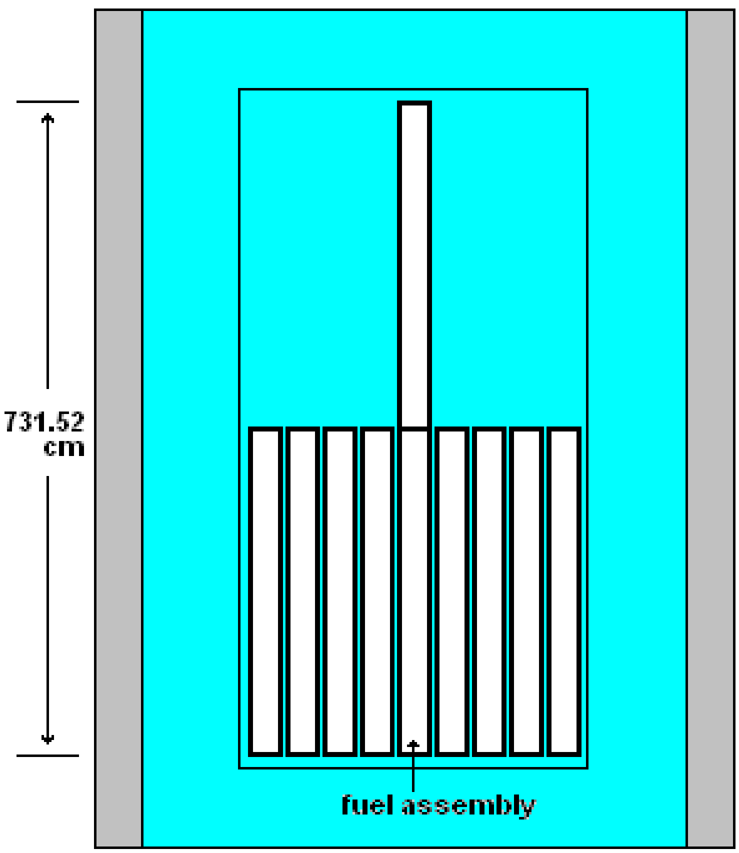

Figure 5.1-9 Axial View of the BWR Storage Rack with One Fuel Assembly Stacked on Top

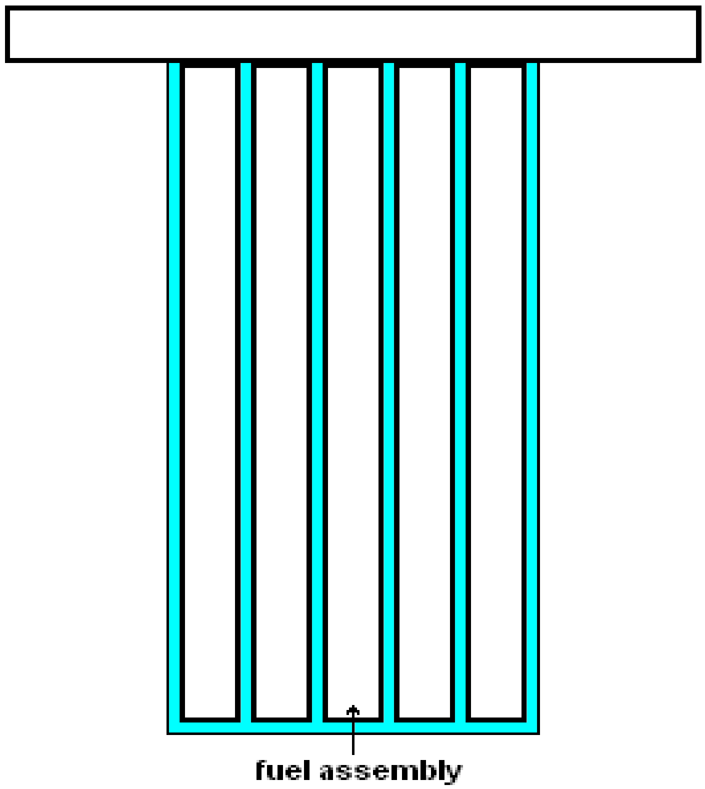

Figure 5.1-10 Axial View of the Horizontally Stacked PWR Fuel Assembly on Top of Storage Rack

Fuel reconfiguration, including compaction and expansion, was evaluated utilizing the MCNP PWR and BWR pin-cell model (Section 5.1.2.1) and material specifications (Section 5.1.2.2). The fuel pin pitches were decreased and increased and varied in increments from beyond the nominal pitch to the minimum pin pitch. Both fully flooded and dry conditions were studied. The RB PWR storage rack configuration was also utilized to study reactivity increase due to fuel expansion.

A single PWR W 17 x 17 OFA was modeled to study a drop to the floor of a single fuel assembly. The dimensions of the fuel assembly are listed in Table 5.1-4 and the material compositions can be found in Table 5.1-5. The fuel enrichment was 5.0 wt %.

5.2 CRITICALITY CALCULATIONS

5.2.1 Determination of Most Reactive Fuel

The selection of PWR and BWR fuel assemblies, to be modeled as a fuel pin cell, for the most reactive fuel analysis was taken from the *GA-4 Legal Weight Truck From-Reactor Spent Fuel Shipping Cask Final Design Report* (General Atomics 1993a, Section 6.4.2) and *GA-9 Legal Weight Truck From-Reactor Spent Fuel Shipping Cask Final Design Report* (General Atomics 1993b, Section 6.4.2), respectively. The pin cells were modeled in MCNP and reflective boundary conditions were used on all sides to simulate an infinite array of fuel pins.

The multiplication factor, k_{inf}, was calculated twice for each PWR fuel pin type utilizing the actual design enrichment (Table 5.1-1) and 5.0 wt % enrichment (Table 5.1-1). The results presented in Table 5.2-1 feature the design enrichment based calculations and show that the Westinghouse 17 x 17 Optimized Fuel Assembly (OFA) is the most reactive PWR fuel. These findings are consistent with those presented in the *GA-4 Legal Weight Truck From-Reactor Spent Fuel Shipping Cask Final Design Report* (General Atomics 1993a, Section 6.4.2). Table 5.2-2 displays the 5.0 wt % enrichment based results (i.e., all pin cell designs have the same initial enrichment) and it shows, however, that the W 14 x 14 OFA has the most reactive fuel (the W 17 x 17 OFA has the second to the highest k_{inf} value). Because of this discovery, a full assembly model was developed in MCNP for both the W 14 x 14 OFA (MCNP files w14-5 and w14-5.out) and W 17 x 17 OFA (MCNP files rb5-asm and rb5-asm.out) with an initial fuel enrichment of 5.0 wt % ^{235}U. The calculated k_{eff} values are 0.82548 ± 0.00043 and 0.83922 ± 0.00047 for the W 14 x 14 OFA and W 17 x 17 OFA, respectively, demonstrating that the W 17 x 17 OFA indeed is the more reactive fuel, and was consequently chosen for the PWR fuel storage rack analysis. Further, the W 17 x 17 OFA was also found to be the most reactive PWR fuel assembly in a storage cask configuration (Holtec International 1996, p. 6.2-1).

Calculations were also performed with the W 14 x 14 OFA and the W 17 x 17 OFA fuel assemblies in the RB storage rack configuration. These calculations also verify that the W 17 x 17 OFA is the more reactive fuel assembly, featuring a k_{eff} of 0.92090 ± 0.00044 (MCNP files rb11-5 and rb11-5.out) while the W 14 x 14 OFA shows a k_{eff} of 0.88706 ± 0.00052 (MCNP files w14-5A and w14-5A.out). The calculations were performed with an initial fuel enrichment of 5.0 wt % ^{235}U and Boral panels included in the storage racks.

Table 5.2-1 Most Reactive PWR Fuel Analysis for Design Enrichment

Manufacturer	Array	Version	k_{inf} (design enr.)	Standard deviation	MCNP files
Westinghouse	17x17	Std.	1.43935	0.00026	w17std, w17std.out
Westinghouse	17x17	OFA	1.45164	0.00026	w17ofa, w17ofa.out
Westinghouse	15x15	Std/ZC	1.44630	0.00025	w15std, w15std.out
Westinghouse	15x15	OFA	1.43498	0.00026	w15ofa, w15ofa.out
Westinghouse	14x14	Std/ZCA Std/ZCB	1.41889	0.00017	w14zc, w14zc.out
Westinghouse	14x14	Model C	1.41294	0.00017	w14mdc,w14mdc.out
Westinghouse	14x14	OFA	1.44575	0.00017	w14ofa, w14ofa.out
B&W	17x17	Mark C	1.38909	0.00017	bw17, bw17.out
B&W	15x15	Mark B,BZ,BGD	1.39254	0.00018	bw15, bw15.out
CE	16x16	St. Lucie	1.43353	0.00017	ce16, ce16.out
CE	15x15	Pallisades	1.38220	0.00017	ce15, ce15.out
CE	14x14	Std/Gen	1.45676	0.00017	ce14, ce14.out
CE	14x14	Ft. Calhoun	1.44453	0.00017	ce14fc, ce14fc.out

Table 5.2-2 Most Reactive PWR Fuel Analysis for 5 wt % U-235

Manufacturer	Array	Version	k_{inf} (5 wt %)	Standard deviation	MCNP files
Westinghouse	17x17	Std.	1.49000	0.00017	w17std5, w17std5.out
Westinghouse	17x17	OFA	1.50521	0.00018	w17ofa5, w17ofa5.out
Westinghouse	15x15	Std/ZC	1.49730	0.00017	w15std5, w15std5.out
Westinghouse	15x15	OFA	1.49730	0.00017	w15ofa5, w15ofa5.out
Westinghouse	14x14	Std/ZCA Std/ZCB	1.49179	0.00018	w14zc5, w14zc5.out
Westinghouse	14x14	Model C	1.49321	0.00018	w14mdc5, w14mdc5.out
Westinghouse	14x14	OFA	1.51186	0.00027	w14ofa5, w14ofa5.out
B&W	17x17	Mark C	1.49214	0.00026	BW175, BW175.out
B&W	15x15	Mark B,BZ,BGD	1.49574	0.00024	BW155, BW155.out
CE	16x16	St. Lucie	1.49228	0.00027	ce165, ce165.out
CE	15x15	Pallisades	1.49279	0.00028	ce155, ce155.out
CE	14x14	Std/Gen.	1.49458	0.00026	ce145, ce145.out
CE	14x14	Ft. Calhoun	1.49496	0.00028	ce14fc5, ce14fc5.out

As for the PWR analysis, the multiplication factor, k_{inf}, was calculated twice for each BWR fuel pin type utilizing 4.5 wt % and 5.0 wt % enrichments (Table 5.1-1). The results presented in Tables 5.2-3 and 5.2-4 show that the GE 7 x 7 Standard fuel assembly is the most reactive BWR fuel. These findings are consistent with those presented in the *GA-9 Legal Weight Truck From-Reactor Spent Fuel Shipping Cask Final Design Report* (General Atomics 1993b, Section 6.4.2).

Table 5.2-3 Most Reactive BWR Fuel Analysis for 4.5 wt % U-235

Manufacturer	Array and Version	k_{inf}	Standard deviation	MCNP files
GE 7x7	7x7	1.48306	0.00017	bwr7x7, bwr7x7.out
GE 8x8	8x8	1.47697	0.00024	bwr8x8, bwr8x8.out

Table 5.2-4 Most Reactive BWR Fuel Analysis for 5.0 wt % U-235

Manufacturer	Array and Version	k_{inf}	Standard deviation	MCNP files
GE 7x7	7x7	1.50116	0.00017	bwr7x75, bwr7x75.out
GE 8x8	8x8	1.49549	0.00026	bwr8x85, bwr8x85.out

To further verify these findings, a full assembly model was developed in MCNP for both the GE 7 x 7 (MCNP files ge7x7 and ge7x7.out) and GE 8 x 8 (MCNP files ge8x8 and ge8x8.out) with an initial fuel enrichment of 5.0 wt % ^{235}U. The calculated k_{eff} values are 0.38939 ± 0.00030 and 0.38455 ± 0.00033 for the GE 7 x 7 assembly and GE 8 x 8 assembly, respectively, again demonstrating that the GE 7 x 7 is the more reactive fuel, and was consequently chosen for the BWR fuel storage rack analysis. In addition, the GE 7 x 7 assembly was also found to be a bounding BWR fuel assembly in a storage cask configuration (Holtec International 1996, p. 6.2-1).

5.2.2 Storage Rack Calculations

The process and methodology for criticality safety analysis given in the *Preclosure Criticality Analysis Process Report* (Scaglione 2003, Section 2.1.7) were implemented in these calculations. This process and methodology require, as stated earlier in Section 2, consideration of the most reactive fuel assembly, the multiplication factor will not exceed 0.95 including all uncertainties and bias, no burnup credit, and no credit for ^{234}U and ^{236}U. Further, all calculations were performed with MCNP and feature flooded fuel pin gaps and only 75 % credit for the fixed neutron absorber was applied. In addition, reflective boundary conditions are applied to all models.

5.2.2.1 Determination of Storage Rack Pitch in DTF

Per Assumption 3.3, PWR storage rack assembly pitches were varied as a function of enrichment to ensure that the resulting k_{eff} to remain below 0.95 (including all bias and uncertainties). The assembly pitch was varied in MCNP between 9 inches (assemblies touching each other) to 11 inches (maximum spacing). Further, the fuel enrichments were varied from 4.0 wt %, 4.5 wt %, and 5.0 wt % to study the impact on reactivity as a function of assembly pitch. The MCNP model features reflective boundary conditions.

The BWR storage rack assembly pitches were also varied as a function of enrichment to ensure that the resulting k_{eff} to remain below 0.95 (including all bias and uncertainties). The assembly pitch was varied in MCNP between 5.75 inches (assemblies touching each other) to 6.5 inches (maximum spacing). Further, the fuel enrichments were varied from 4.0 wt %, 4.5 wt %, and 5.0 wt % to study the impact on reactivity as a function of assembly pitch. The MCNP model features reflective boundary conditions.

5.2.2.2 Moderator Density Variations in the DTF

Moderator density, which could vary from dry to fully moderated conditions under accident conditions, was varied in the MCNP model over the range of 0.0 to 1.0 g/cm^3. In addition, various assembly pitches were introduced in the model (9.0, 10.0, and 11.0 inch assembly pitches) as a function of moderator variations. The MCNP model also includes a 5.0 wt % fuel enrichment and reflective boundary conditions.

5.2.2.3 Moderator Intrusion in the RB

Effects of potential moderator intrusion into the RB PWR storage area were modeled in MCNP by varying the moderator height to cover the active fuel region between 0 % - 100%. Note that the RB PWR fuel storage is in the pool. Moderator intrusion as used here implies presence of water at different levels. The MCNP model features an assembly pitch of 11 inches, 5.0 wt % enrichment and reflective boundary conditions.

5.2.2.4 RB Storage Rack Pitch Calculation

The PWR storage rack configuration for the RB was analyzed for maximum assembly pitches (e.g., 11 and 11.25 inches) and enrichment (e.g., 5.0 wt %) in order to ensure that the configuration meets design criteria (Minwalla 2003, Section 4.9.2.2). The BWR storage rack configuration for the RB (Section 5.1.4) was also analyzed for a 6.25 in assembly pitch and 5.0 wt % enrichment. Both the PWR and BWR MCNP models include reflective boundary conditions.

5.2.3 Category 1 and 2 Event Sequences

This design calculation considered Category 1 and Category 2 event sequences as identified in the *Preliminary Categorization of Event Sequences for License Application* (BSC 2003a, Section 7). It should be mentioned that Section 7 of BSC 2003a does not identify any criticality events as Category 1 or Category 2 because it takes credit for criticality controls and design features such as those identified in the present document. Consequently, all potential events in the surface facilities that were listed under the category of "Fissile" (BSC 2003a, Section 6.3) have also been included in the evaluation presented below. The *Preliminary Categorization of Event Sequences for License Application* document makes no statement as to the frequency or credibility of these events, but instead shows that given the occurrence of any one event, criticality does not occur. As stated in Minwalla 2003 (Section 4.9.2.2), this is sufficient to satisfy the criticality safety principle of double contingency. The simultaneous occurrence of two or more events listed here is beyond the scope of the required analysis (Minwalla 2003, Section 4.9.2.2).

Table 5.2-5 describes the Category 1 event sequences and the applicable criticality safety evaluation performed for each event. Table 5.2-6 provides the criticality evaluation for the Category 2 event sequences. Note that the Category 2 event sequences not pertaining to the scope of this calculation were not included in the evaluation below. Table 5.2-7 presents the additional potential criticality events. The supporting calculations for the criticality events and event sequences are provided in the subsections.

Table 5.2-5 Criticality Safety Evaluation for Category-1 Event Sequences (DTF)

Event No.	Event Description [a]	Criticality Safety Evaluation
1-01	Generalized drop involving a CSNF[b] assembly	This event is a generalized event including many different types of drops and many different consequences, including but not limited to criticality. See Table 5.2-7 for a criticality evaluation of specific bounding drop events.
1-02	Generalized collision involving a CSNF assembly	This event is a generalized event including many different types of collisions and many different consequences, including but not limited to criticality. See Table 5.2-7 for a criticality evaluation of specific bounding collision events.

[a] BSC 2003a, Section 7
[b] Commercial Spent Nuclear Fuel

Table 5.2-6 Criticality Safety Evaluation for Category-2 Event Sequences (DTF and RB)

Event No.	Event Description [a]	Criticality Safety Evaluation
2-03	Drop of cask outer lid from the crane onto the cask	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
2-06	Drop of inner lid of a transportation cask or WP into a transportation cask or WP	The WP design should provide criticality safety for this event.
2-07 2-21	Drop of a DPC [b]	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
2-09	Drop or collision of a WP inner lid from the transfer cell crane onto a loaded WP	The WP design should provide criticality safety for this event.
2-10	Generalized drop of handling equipment onto a CSNF assembly	The drop could cause reconfiguration of the CSNF assembly. Section 5.2.3.1 evaluates the k_{eff} of a reconfigured, fully flooded, CSNF and it remains safely below 0.9.
2-11	Drop or collision of severed lid back into DPC from the crane	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
2-12	Drop or collision of a seal ring into the open DPC	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
2-13	Drop of load-port cover into open DPC	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
2-14	Uncontrolled descent of hydraulic jack pad holding a loaded canister (opened or unopened)	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
2-15	Drop of the cover of a WP load port from the crane onto the inner lid of a WP	The WP design should provide criticality safety for this event.
2-17	Drop or collision of a loaded WP or transportation cask from the crane	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for the event with the transportation cask. The WP design should provide criticality safety for the event involving the WP.

Table 5.2-6 Criticality Safety Evaluation for Category-2 Event Sequences (DTF and RB)

Event No.	Event Description [a]	Criticality Safety Evaluation
2-18 2-19	Drop or collision of a lid grapple or lid into a loaded WP or transportation cask	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for the event with the transportation cask. The WP design should provide criticality safety for the event involving the WP.
2-20 2-28	Drop or collision of a CSNF assembly	The fuel assemblies are transferred one at a time and a single flooded fuel assembly has a k_{eff} of less than 0.9. Therefore, criticality safety is not an issue for this event (see supporting calculations in Section 5.2.3.1). In addition, a potential reconfiguration of a fuel assembly will not pose a criticality concern (see supporting calculations in Section 5.2.3.2).
2-24	Handling Equipment Drop into an open WP or transportation cask	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for the event with the transportation cask. The WP design should provide criticality safety for the event involving the WP.
2-25	Drop or collision of a loaded transportation cask (without impact limiters) from crane	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
2-26	Drop or collision of a lid grapple or lid onto a loaded WP or transportation cask	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for the event with the transportation cask. The WP design should provide criticality safety for the event involving the WP.
2-27	Drop or collision of equipment onto the lid of a transportation cask	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
2-29	Drop or collision of equipment or a lid onto a CSNF assembly in a transportation cask	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
2-30	Drop or collision of handling equipment in the pool onto CSNF in the staging rack	While k_{eff} will increase if assemblies were reconfigured due to the drop or collision, this event will still not pose a criticality concern as demonstrated by fuel reconfiguration calculations in Section 5.2.3.2

[a] BSC 2003a, Section 7
[b] Dual-Purpose Canister

Table 5.2-7 Additional Criticality Related Events

Section [a]	Criticality Event Description	Criticality Safety Evaluation
6.3.7.4.1 6.3.17.6.3	Drop of an individual SFA[b] back into a transportation cask	SFA drop back into the transportation cask will return to its original position in the cask. Since the transportation cask is NRC-certified to be 10 CFR 71 compliant, the criticality evaluation performed for the cask certification is adequate to cover this event.
6.3.16.5.2	Drop of a CSNF[c] assembly in a WP[d] or transportation cask	For the transportation cask scenario, see the evaluation for the event above. For the WP scenario, the WP design should provide criticality safety for this event.
6.3.7.4.2 6.3.17.6.2	Drop of an individual SFA back into a staging rack	SFA drop back into the staging rack will return to its original position in the staging rack. Section 6 shows that a fully loaded staging rack meets the criticality design criteria. In addition, events when a SFA drops onto a fully loaded staging rack have been evaluated in Section 5.2.3.3. The increase in reactivity is rather inconsequential, and would not case k_{eff} to exceed the nominal value used in this design calculation for criticality safety. Further, evaluations for a damaged SFA (i.e., reconfigured) has been evaluated in Section 5.2.3.2 and demonstrates that criticality safety design limits are met.
6.3.8.5.2	Drop of a SFA and re-arrangement of the orientation of the SFA in the staging rack	See the evaluation for the previous event. Also, evaluations have been done in Section 5.2.3.2 for fuel reconfiguration and it was found that k_{eff} would not exceed the nominal value used in this design calculation for criticality safety.
6.3.16.5.3	Drop of a loaded transportation cask	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
6.3.17.6.1	Collision of a transportation cask	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
6.3.7.4.5 6.3.8.5.5	Misload of a WP	Fuel assembly misloading is not an issue for “out-of-package” criticality, as this criticality evaluation is based on 5% maximum enrichment and no burnup credit is taken.
6.3.7.4.6 6.3.8.5.6 6.3.17.6.6	Misload of a CSNF staging rack	Fuel assembly misloading is not an issue for “out-of-package” criticality, as this criticality evaluation is based on 5% maximum enrichment and no burnup credit is taken.
6.3.8.5.1	Drop of an SFA back into a DPC and re-arrangement of canister internals	Commercial SNF DPC meets the storage and transportation requirements under 10 CFR 72 and 10 CFR 71, respectively. Regulatory compliance with 10 CFR 71 and 72 provides assurance of criticality safety for this event.
6.3.7.4.3	Drop of a DPC	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
6.3.8.5.3	Drop of DPC from crane and a re-arrangement of canister internals	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.
6.3.8.5.4	Fall of a trolley holding a DPC (opened or un-opened) and re-arrangement of canister internals	Regulatory compliance with 10 CFR 50, 71 and 72 provides assurance of criticality safety for this event.

[a] BSC 2003a
[b] Spent Fuel Assembly
[c] Commercially Spent Nuclear Fuel
[d] Waste Package

5.2.3.1 Single and Multiple Spent Fuel Assembly Drop

Category 1 and 2 event sequences include potential drops of single fuel assemblies on a floor, empty rack, empty cask or empty waste package as well as collision with handling equipment, building wall, etc. For this purpose, a single PWR W 17 x 17 OFA (most reactive fuel type) was modeled in MCNP. The fuel assembly was intact and fully flooded, representing the most reactive configuration. Compression or compaction of the fuel assembly after the drop would result in a less reactive condition as compared to the intact condition, as demonstrated in Section 5.2.3.2. However, expansion of the fuel assembly after the drop would result in a higher reactive condition. Quantification of the reactivity increase is presented in Section 5.2.3.2.

Table 5.2-8 lists the k_{eff} of a single PWR fuel assembly (un-poisoned) and it can be seen that the reactivity is considerably below the design criteria limit of 0.95 (Minwalla 2003, Section 4.9.2.2). In addition, a calculation of a single PWR fuel assembly (un-poisoned) with the pin pitch reconfigured to its maximum (see Table 5.2-11 in Section 5.2.3.2) was also performed. It can be seen from the table that this case is well within the design criteria limit. Consequently, a drop of a single fuel assembly does not pose a criticality safety concern. The table further shows multiple (un-poisoned) PWR assemblies stacked together. It can be seen that it takes at least three PWR fuel assembles in order to pose a criticality safety concern.

Table 5.2-8 K_{eff} of Single and Multiple PWR W 17 x17 Assemblies

Enrichment (wt %)	K_{eff}	St. Dev.	MCNP files
PWR W 17 x17 OFA (1 assembly - regular pitch)			
5.0	0.83922	0.00047	rb5-asm, rb5-asm.out
PWR W 17 x17 OFA (1 assembly - expanded pitch)			
5.0	0.87797	0.00049	rb-asmB, rb-asmB.out
PWR W 17 x17 OFA (2 assemblies)			
5.0	0.90122	0.00042	rb5asm2, rb5asm2.out
PWR W 17 x17 OFA (3 assemblies)			
5.0	0.99777	0.00045	rb5asm3, rb5asm3.out
PWR W 17 x17 OFA (4 assemblies)			
5.0	1.13503	0.00054	rb5asm4, rb5asm4.out

5.2.3.2 Fuel Reconfiguration

In the event of a drop or collision, fuel may be reconfigured into a new geometry, i.e., either a pitch reduction or increase. In the event of a pitch reduction, this can be modeled by decreasing the fuel pin pitch in the MCNP model. This scenario was evaluated utilizing the MCNP PWR and BWR pin cell models (Section 5.1.2.1), and featuring reflective boundary conditions to simulate an infinite array of fuel pins. The pin cell model was fully flooded. Also, note that this study was performed to demonstrate the trends of k_{inf} (i.e., not an absolute value) from a drop event, which would result in a pin pitch reduction (due to impact).

Table 5.2-9 shows k_{inf} versus pin pitch for PWR and BWR fuel modeled as an array of infinite pin cells (Section 5.2.1). The table indicates that in the event of reduction in fuel pin pitch, the reactivity will decrease. Consequently, this accident scenario meets the nuclear criticality safety design criteria.

Table 5.2-9 K_{inf} of Pin Pitch Reduction of PWR and BWR Fuel

Pin Pitch (cm)	K_{eff}	St. Dev.	MCNP files
PWR Fuel (W17 x 17 OFA pin cell model, 5.0 wt % enrichment)			
1.25984 (regular)	1.50521	0.00018	w17ofa5, w17ofa5.out
1.20	1.48433	0.00024	w17o12, w17o12.out
1.10	1.42603	0.00020	w17o11, w17o11.out
1.00	1.32650	0.00020	w17o10, w17o10.out
0.9145 (smallest)	1.18456	0.00020	w17o09, w17o09.out
BWR Fuel (GE 7 x7 Std pin cell model, 4.5 wt % enrichment)			
1.87452 (regular)	1.48306	0.00017	bwr7x7, bwr7x7.out
1.80	1.46316	0.00019	bwr18, bwr18.out
1.70	1.42416	0.00019	bwr17, bwr17.out
1.60	1.36543	0.00019	bwr16, bwr16.out
1.50	1.27844	0.00020	bwr15, bwr15.out
1.43003 (smallest)	1.19414	0.00020	bwr14, bwr14.out

The same scenario (i.e., pin pitch reduction) was also studied for PWR and BWR fuel in a completely dry environment. As before, this was evaluated utilizing the MCNP PWR and BWR pin cell models (Section 5.1.2.1), and featuring reflective boundary conditions to simulate an infinite array of fuel pins. Table 5.2-10 shows k_{inf} versus pin pitch for PWR and BWR fuel. The table indicates that this accident scenario also meets the nuclear criticality safety design criteria.

Table 5.2-10 K_{inf} of Pin Pitch Reduction of PWR and BWR Fuel (Dry Conditions)

Pin Pitch (cm)	K_{eff}	St. Dev.	MCNP files
PWR Fuel (W17 x 17 OFA pin cell model, 5.0 wt % enrichment)			
1.4	0.77376	0.00017	w17o14D, w17o14D.out
1.3	0.77377	0.00015	w17o13D, w17o13D.out
1.25984 (regular)	0.77368	0.00016	w17ofa5D, w17ofa5D.out
1.20	0.77394	0.00015	w17o12D, w17o12D.out
1.10	0.77362	0.00016	w17o11D, w17o11D.out
1.00	0.77343	0.00019	w17o10D, w17o10D.out
0.9145 (smallest)	0.77368	0.00016	w17o09D, w17o09D.out
BWR Fuel (GE 7 x7 Std pin cell model, 5.0 wt % enrichment)			
2.1	0.77856	0.00016	bwr21D, bwr21D.out
1.95	0.77890	0.00015	bwr195D, bwr195D.out
1.87452 (regular)	0.77884	0.00012	bwr7x75D, bwr7x75D.out
1.80	0.77873	0.00017	bwr18D, bwr18D.out
1.70	0.77896	0.00016	bwr17D, bwr17D.out
1.60	0.77897	0.00016	bwr16D, bwr16D.out
1.50	0.77901	0.00023	bwr15D, bwr15D.out
1.43003 (smallest)	0.77899	0.00017	bwr14D, bwr14D.out

In the event of a pitch increase, this can be modeled by increasing the fuel pin pitch in the MCNP model. This scenario was evaluated utilizing the MCNP PWR and BWR pin cell models (Section 5.1.2.1), and featuring reflective boundary conditions to simulate an infinite array of fuel pins. The pin cell model was fully flooded. Also, note that this study was performed to demonstrate the trends of k_{inf} (i.e., not an absolute value) from a drop event, which would result in a pin pitch increase (due to impact).

Table 5.2-11 shows k_{inf} versus pin pitch for PWR and BWR fuel modeled as an array of infinite pin cells (Section 5.2.1). The table indicates that in the event of increase in fuel pin pitch, the reactivity will increase. Figure 5.2-1 graphically displays the results presented in Table 5.2-11 and shows that the peak in k_{inf} occurs at a pin pitch of 1.45 cm for PWR fuel and 2.15 cm for BWR fuel.

Table 5.2-11 K_{inf} of Pin Pitch Increase of PWR and BWR Fuel (Flooded Conditions)

Pin Pitch (cm)	K_{eff}	St. Dev.	MCNP files
PWR Fuel (W17 x 17 OFA pin cell model, 5.0 wt % enrichment)			
1.20	1.48433	0.00024	w17o12, w17o12.out
1.30	1.51560	0.00025	w17o13, w17o13.out
1.40	1.52855	0.00025	w17o14, w17o14.out
1.45	1.53041	0.00021	w17o145, w17o145.out
1.50	1.52921	0.00021	w17o15, w17o15.out
1.60	1.52066	0.00022	w17o16, w17o16.out
1.70	1.50493	0.00021	w17o17, w17o17.out
1.80	1.48424	0.00020	w17o18, w17o18.out
1.90	1.45839	0.00022	w17o19, w17o19.out
BWR Fuel (GE 7 x7 Std pin cell model, 5.0 wt % enrichment)			
1.87452 (regular)	1.50116	0.00017	bwr7x75, bwr7x75.out
1.95	1.51473	0.00023	bwr195, bwr195.out
2.1	1.52811	0.00022	bwr21, bwr21.out
2.15	1.52924	0.00022	bwr215, bwr215.out
2.2	1.52851	0.00023	bwr22, bwr22.out
2.3	1.52309	0.00019	bwr23, bwr23.out
2.5	1.50050	0.00022	bwr25, bwr25.out

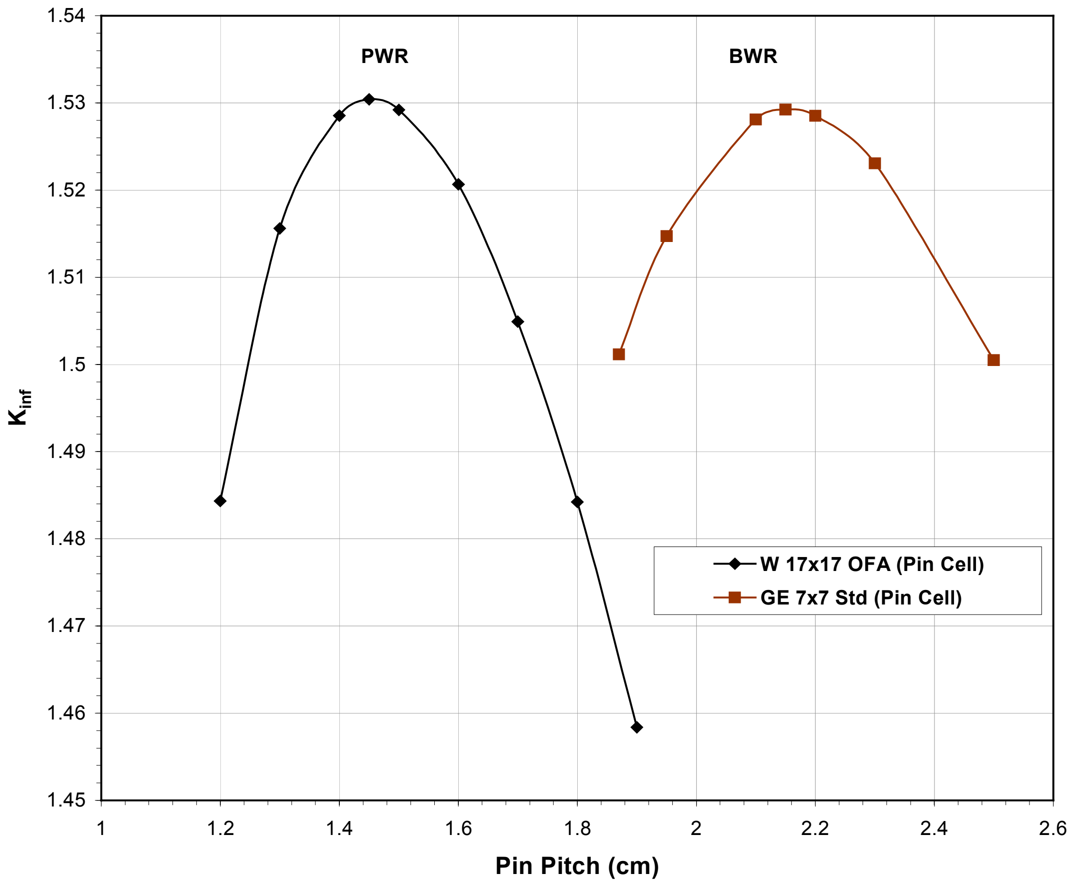

Figure 5.2-1 PWR and BWR Pin Pitch versus k_{inf} for Various Distances

In comparing the slopes (between optimum and peak pitch) of the PWR and BWR graphs in Figure 5.2-1, the reactivity increase of BWR fuel due to reconfiguration is predicted to be less than that of the PWR fuel. Consequently, the accident conditions described below were only considered for PWR fuel.

Calculations were performed for the RB PWR fuel storage configurations (11.25 in. assembly pitch and 5.0 wt % enrichment) featuring the following fuel reconfigurations:

a) the top 28 cm of the center fuel assembly reconfigured to a pin pitch of 1.45 cm (worst pin pitch per Table 5.2-11);
b) the top 50 cm of the center fuel assembly reconfigured to a pin pitch of 1.45 cm;

Spacers, preventing the fuel from bowing out, are located near the end, as well as approximately 28 cm and 50 cm from the ends, of the fuel assembly (DOE 1987, p. 2A-353). Consequently, modeling 30 cm as reconfigured would be realistic while 50 cm is conservative. Modeling the top portion of a fuel assembly as reconfigured will simulate a drop (or slap down) of an assembly, as well as simulate a drop of an item on top of the assembly. Table 5.2-12 shows k_{eff} for a RB PWR storage rack configuration including a 28 cm (case a) and a 50 cm (case b) reconfigured fuel assembly for the top portion of the fuel compared to the k_{eff} of a regular RB PWR storage rack. It can be seen from the table that the increase in reactivity (i.e., Δk) is fairly substantial when fuel reconfiguration occurs. However, the PWR accident condition still meets the design criteria.

Table 5.2-12 K_{eff} of Fuel Reconfiguration in the RB Fuel Storage Rack

Pitch (in.)	Enrichment (wt%)	K_{eff} (reconfig. fuel)	St. Dev.	MCNP files	K_{eff} (regular rack)	St. Dev.	MCNP files	Δk
RB PWR Storage Rack Configuration –28 cm reconfigured								
11.25	5.0	0.90958	0.00033	rb1125B2, rb1125B2.out	0.90893	0.00033	rb125-5, rb125-5.out	0.00065
RB PWR Storage Rack Configuration –50 cm reconfigured								
11.25	5.0	0.91365	0.00036	rb1125B, rb1125B.out	0.90893	0.00033	rb125-5, rb125-5.out	0.00472

In the event that a larger item (e.g., handling equipment, lid) is dropped on top of the storage rack (see Table 5.2-6) it could potentially damage more than one fuel assembly in the storage rack. If a whole row of assemblies (i.e., 5 fuel assemblies) is damaged (worst case scenario), the k_{eff} for a 28 cm of fuel reconfiguration is approximately 0.912 (adding five Δk's to the regular rack k_{eff} in Table 5.2-11) and approximately 0.933 for the 50 cm of fuel reconfiguration scenario. Though this calculation is inherently conservative (e.g., fully flooded scenario, fully loaded storage rack, uniform and most reactive pin pitch, conservative damage length), a drop (or slap down) of an assembly or a drop of an item on top of the assemblies will not pose a criticality concern.

5.2.3.3 Vertical and Horizontal Fuel Stacking

Criticality evaluations were performed for a vertical double fuel stacking configuration for both the DTF PWR and BWR storage racks to ensure criticality safety per the *Project Design Criteria Document* (Minwalla 2003, Section 4.9.2.2). The MCNP model contains a full rack with one fuel assembly vertically stacked on top of the rack (see Figure 5.1-9). The model also features reflective boundary conditions. The assembly pitch for the PWR storage rack is 11 inches and the assembly pitch for the BWR storage rack is 6.0 inches. The initial enrichment is 5.0 wt % in both the PWR and BWR cases.

Horizontal fuel stacking was also evaluated for the RB PWR storage racks to ensure criticality safety. The MCNP model contains a full rack with one fuel assembly horizontally stacked on top of the rack (see Figure 5.1-10). The model also features reflective boundary conditions and the assembly pitch for the PWR storage rack is 11 in. with initial enrichment of 5.0 wt %.

Table 5.2-13 shows k_{eff} for a vertical double fuel stacking configuration for both the DTF PWR and BWR storage racks compared to the k_{eff} of a regular PWR and BWR storage rack. It can be seen from the table that the increase in reactivity (i.e., Δk) is very small when fuel stacking occurs. Consequently, both the PWR and BWR accident condition meets the design criteria.

Table 5.2-14 shows k_{eff} for a horizontal double fuel stacking configuration for the RB storage rack compared to the k_{eff} of a regular PWR storage rack. It can be seen from the table that the increase in reactivity (i.e., Δk) is very small when horizontal fuel stacking occurs and will not jeopardize meeting criticality design criteria.

Table 5.2-13 K_{eff} of Vertical Fuel Stacking in the DTF Fuel Storage Rack

Pitch (in.)	Enrichment (wt%)	K_{eff} (stacked fuel)	St. Dev.	MCNP files	K_{eff} (regular rack)	St. Dev.	MCNP files	Δk
PWR Fuel Assembly								
11	5.0	0.91136	0.00036	p11-5S, p11-5S.out	0.91060	0.00032	p11-5n, p11-5n.out	0.00076
BWR Fuel Assembly								
6.0	5.0	0.91207	0.00039	9b6S5-1, 9b6S5-1.out	0.91149	0.00040	9b-50, 9b-50.out	0.00058

Table 5.2-14 K_{eff} of Horizontal Fuel Stacking in the RB Fuel Storage Rack

Pitch (in.)	Enrichment (wt%)	K_{eff} (stacked fuel)	St. Dev.	MCNP files	K_{eff} (regular rack)	St. Dev.	MCNP files	Δk
PWR Fuel Assembly								
11	5.0	0.90986	0.00043	rb11H5, rb11H5.out	0.90930 [a]	0.00041	rb11H5a, rb11H5a.out	0.00056

[a] K_{eff} is lower than for the regular RB criticality calculation because some of some non-conservative variations in the model. However, the trends in reactivity seen in this table are still applicable to the regular RB criticality calculation.

6. RESULTS AND CONCLUSIONS

This section presents the results of the criticality calculations and makes recommendations for additional criticality safety design features as appropriate. The outputs presented in this document are all reasonable compared to the inputs. The uncertainties are taken into account by consistently using a conservative approach, which is the result of the methods and assumptions described in Sections 2 and 3, respectively.

6.1 PWR FUEL STORAGE RACK

Table 6.1-1 shows the k_{eff} values of the PWR storage rack with varied assembly pitch configuration as a function of enrichment. The k_{eff} values are presented for storage rack configurations with and without fixed neutron absorber (i.e., Boral panel). Per Assumption 3.3, it can be seen that in order for the resulting k_{eff} to remain below 0.95 (including all bias and uncertainties), the storage rack should be designed with 11 inch wide assembly spacing for the highest enrichment (i.e., 5.0 wt %). If a lower enrichment will be considered (i.e., 4.0 or 4.5 wt %), a 10.5 in. assembly spacing can be implemented. Figure 6.1-1 displays k_{eff} and the upper sub-critical limit (USL) versus the assembly pitch for 4.0, 4.5 and 5.0 wt % enrichment.

Table 6.1-1 also displays the reactivity worth of the neutron absorber as a function of assembly pitch and enrichment. It can be seen that the reactivity worth is the highest for a 10 in. assembly pitch and 5.0 wt % enrichment.

Table 6.1-1 PWR Storage Rack Assembly Pitch versus Enrichment with and without Neutron Absorber

Pitch (in.)	Enrichment (wt %)	With neutron absorber			Without neutron absorber			Reactivity worth (Δk)
		K_{eff}	St. Dev.	MCNP files	K_{eff}	St. Dev.	MCNP files	
9	4.0	1.10524	0.00046	p9-40, p9-40.out	1.33656	0.00044	p9-40np, p9-40np.out	0.23132
	4.5	1.13252	0.00046	p9-45, p9-45.out	1.36445	0.00045	p9-45np, p9-45np.out	0.23193
	5.0	1.15546	0.00042	p9-50, p9-50.out	1.38631	0.00043	p9-50np, p9-50np.out	0.23085
10	4.0	0.95750	0.00042	p10-40, p10-40.out	1.23394	0.00042	p10-4np, p10-4np.out	0.27644
	4.5	0.98040	0.00042	p10-45, p10-45.out	1.26119	0.00042	p10N45, p10N45.out	0.28079
	5.0	0.99942	0.00043	p10-50, p10-50.out	1.28343	0.00039	p10-5np, p10-5np.out	0.28401
10.5	4.0	0.90406	0.00041	p105-40, p105-40.out	1.16864	0.00043	p105N4, p105N4.out	0.26458
	4.5	0.92609	0.00046	p105-45, p105-45.out	1.19469	0.00040	p105N45, p105N45.out	0.26860
	5.0	0.94381	0.00048	p105-50, p105-50.out	1.21650	0.00048	p105N5, p105N5.out	0.27269
11	4.0	0.86572	0.00041	p11-40, p11-40.out	1.10713	0.00043	p11-4np, p11-4np.out	0.24141
	4.5	0.88732	0.00043	p11-45, p11-45.out	1.13215	0.00040	p11N45, p11N45.out	0.24483
	5.0	0.91060	0.00032	p11-5n, p11-5n.out	1.15281	0.00038	p11-5np, p11-5np.out	0.24221

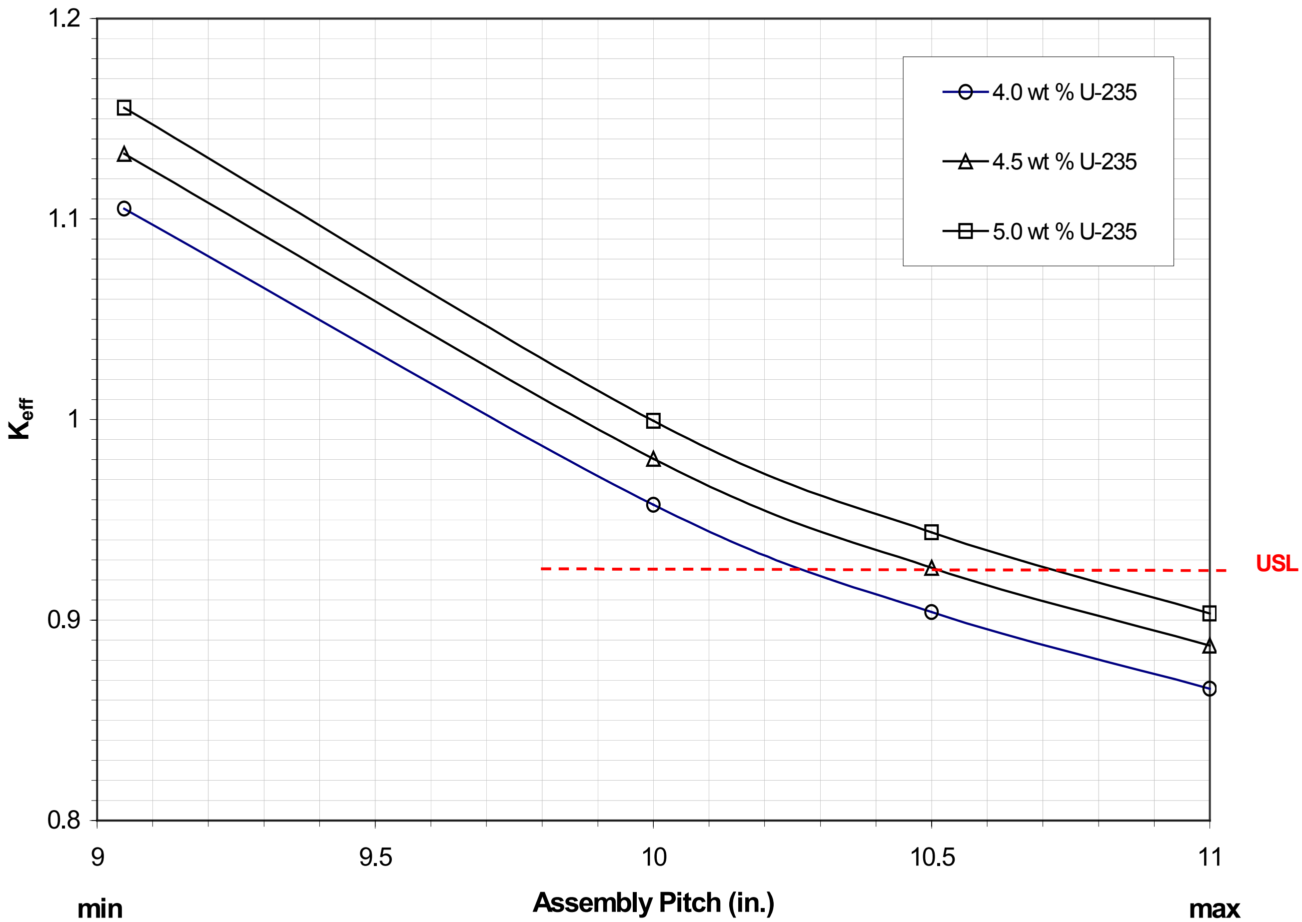

Figure 6.1-1 PWR Storage Rack Assembly Pitch versus k_{eff} for Various Enrichments

Moderator density, which could vary from dry to fully moderated conditions under accident conditions, has been varied over the range of 0.0 to 1.0 g/cm^3. Table 6.1-2 displays k_{eff} as a function of moderator density for 5.0 wt % enrichment and various storage rack assembly pitches. It can be seen that the reactivity of the loaded storage rack decreases with reduction in moderator density. Figure 6.1-2 shows k_{eff} as a function of moderator variations for 9.0, 10.0, and 11.0 inch assembly pitches with 5.0 wt % enrichment. Also, note that the upper sub-critical limit (USL) is displayed on the graph.

Table 6.1-2 Moderator Density Variations at Various Assembly Pitches for 5.0 wt % Enrichment

Density (g/cm^3)	9 in. pitch			10 in. pitch			11 in. pitch		
	K_{eff}	St. Dev.	MCNP files [a]	K_{eff}	St. Dev.	MCNP files [b]	K_{eff}	St. Dev.	MCNP files [c]
1.0	1.15546	0.00042	p9-50, p9-50.out	0.99942	0.00043	p10-50, p10-50.out	0.91060	0.00032	p11-5n, p11-5n.out
0.98	1.15123	0.00047	p9-98, p9-98.out	0.99383	0.00047	p10-98, p10-98.out	0.89884	0.00042	p11-98, p11-98.out
0.95	1.14242	0.00048	p9-95, p9-95.out	0.98783	0.00043	p10-95, p10-95.out	0.88937	0.00047	p11-95, p11-95.out
0.5	0.94761	0.00039	pwr-05 pwr-05.out	0.83638	0.00043	pwr-05 pwr-05.out	0.73565	0.00039	pwr-05 pwr-05.out
0.3	0.78409	0.00034	pwr-03 pwr-03.out	0.71896	0.00036	pwr-03 pwr-03.out	0.65230	0.00033	pwr-03 pwr-03.out
0.1	0.55769	0.00025	pwr-01 pwr-01.out	0.53708	0.00026	pwr-01 pwr-01.out	0.51859	0.00027	pwr-01 pwr-01.out
0.08	0.53435	0.00026	pwr-008 pwr-008.out	0.51768	0.00023	pwr-008 pwr-008.out	0.50286	0.00024	pwr-008 pwr-008.out
0.05	0.50427	0.00023	pwr-005 pwr-005.out	0.49201	0.00022	pwr-005 pwr-005.out	0.48067	0.00021	pwr-005 pwr-005.out
0.035	0.49064	0.00020	pwr0035 pwr0035.out	0.48034	0.00020	pwr0035 pwr0035.out	0.47122	0.00021	pwr0035 pwr0035.out
0.01	0.46081	0.00016	pwr-001 pwr-001.out	0.45079	0.00018	pwr-001 pwr-001.out	0.44222	0.00018	pwr-001 pwr-001.out
0.005	0.44853	0.00016	pwr0005 pwr0005.out	0.43769	0.00016	pwr0005 pwr0005.out	0.42711	0.00016	pwr0005 pwr0005.out
0.0	0.43052	0.00014	pwr-0 pwr-0.out	0.41606	0.00015	pwr-0 pwr-0.out	0.40273	0.00015	pwr-0 pwr-0.out

[a] Files, except for p9-50 and p9-50.out, are located in directory PWR/9-PITCH
[b] Files, except for p10-50 and p10-50.out, are located in directory PWR/10-PITCH
[c] Files, except for p11-5, p11-5.out, and pwr-05.out are located in directory PWR/11-PITCH

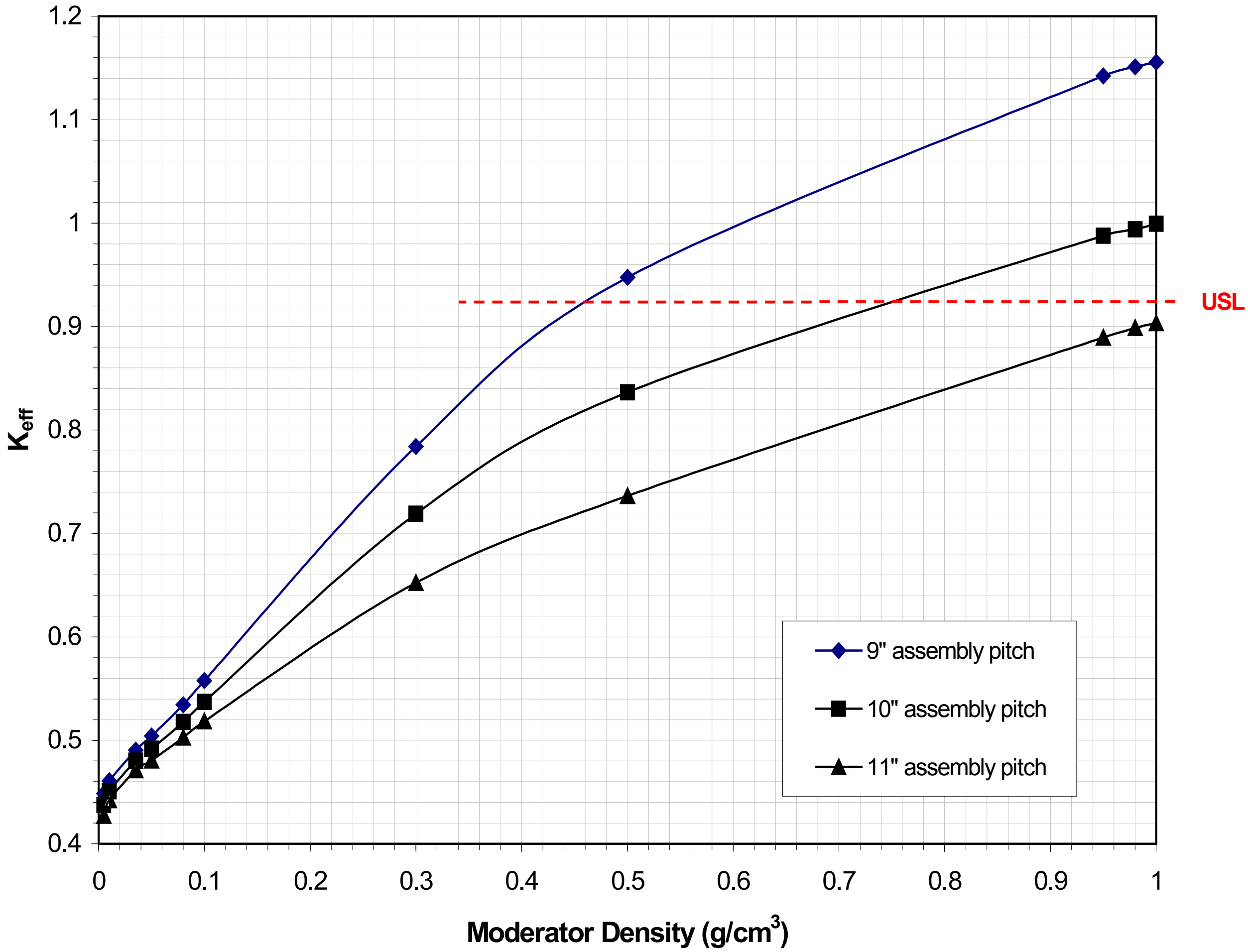

Figure 6.1-2 Moderator Density Variations versus k_{eff} for Various PWR Assembly Pitches

The PWR storage rack configuration for the RB (Section 5.1.4) was analyzed for an 11 in. and 11.25 in. assembly pitch and 5.0 wt % enrichment. Table 6.1-3 displays the k_{eff} values and it can be seen that although it is higher than that for the DTF configuration (Table 6.1-1), an 11.25 in. assembly pitch meets the design criteria (i.e., k_{eff} of 0.95 including bias and uncertainties per Assumption 3.3). It should also be mentioned that there is 'extreme' conservatism (e.g., uniform 5.0 wt % enrichment) built into the calculation so an 11 in. assembly pitch may be acceptable. However, this conservatism would need to be quantified in future work in order to justify a reduced pitch.

Table 6.1-3 K_{eff} of the RB PWR Storage Configuration

Pitch (in.)	Enrichment (wt%)	K_{eff}	St. Dev.	MCNP files
11	5.0	0.92748	0.00031	rb11-5w, rb11-5w.out
11.25	5.0	0.90893	0.00033	rb125-5, rb125-5.out

The effects of potential moderator intrusion into the RB PWR storage area have been evaluated. Table 6.1-4 presents the k_{eff} values as a function of moderator height (1.0 g/cm^3 moderator density) for an assembly pitch of 11 inches and 5.0 wt % enrichment. Note that an 11 in. pitch was used to demonstrate the trends of moderator intrusion. It can be seen that moderator intrusion of the fuel storage rack will increase $k_{eff.}$ However, the nominal calculated k_{eff} remains the highest, providing defense in depth in the event of moderator intrusion.

Table 6.1-4 K_{eff} Values as a Function of Moderator Height

Moderator height (%)	K_{eff}	St. Dev.	MCNP files
0	0.39834	0.00013	rb11-0n, rb11-0n.out
28	0.90911	0.00034	rb11-25n, rb11-25n.out
50	0.92142	0.00041	rb11-50n, rb11-50n.out
78	0.92617	0.00039	rb11-75n, rb11-75n.out
88	0.92654	0.00037	rb11-88n, rb11-88n.out
100	0.92748	0.00031	rb11-5w, rb11-5w.out

6.2 BWR FUEL STORAGE RACK

The k_{eff} values are presented in Table 6.2-1 for the DTF BWR storage rack configurations with and without fixed neutron absorber (i.e., Boral panel) at varied assembly pitch configuration and as a function of enrichment. For the resulting k_{eff} to remain below 0.95 (including all bias and uncertainties per Assumption 3.3), the storage rack should be designed with 6.0 in. wide assembly spacing for all enrichments (i.e, 4.0, 4.5, and 5.0 wt %). Figure 6.2-1 displays k_{eff} versus the assembly pitch for 4.0, 4.5 and 5.0 wt % enrichment with the upper sub-critical limit (USL) identified.

In addition, the reactivity worth of the neutron absorber as a function of assembly pitch and enrichment can also be seen in Table 6.2-1. The reactivity worth is the highest for a 6.5 in. assembly pitch and 5.0 wt % enrichment.

Table 6.2-1 BWR Storage Rack Assembly Pitch versus Enrichment with and without Neutron Absorber

Pitch (in.)	Enrichment (wt %)	With neutron absorber			Without neutron absorber			Reactivity worth (Δk)
		K_{eff}	St. Dev.	MCNP files	K_{eff}	St. Dev.	MCNP files	
5.75	4.0	0.93191	0.00034	9b575-4, 9b575-4.out	1.30117	0.00030	9b575np4, 9b575np4.out	0.36926
	4.5	0.95810	0.00036	9b575-45, 9b575-45.out	1.32858	0.00032	9b57np45, 9b57np45.out	0.37048
	5.0	0.98185	0.00041	9b575, 9b575.out	1.35114	0.00031	9b575np, 9b575np.out	0.36929
6.0	4.0	0.86434	0.00038	9b6-40, 9b6-40.out	1.26929	0.00031	9b6np40, 9b6np40.out	0.40495
	4.5	0.89041	0.00036	9b6-45, 9b6-45.out	1.29686	0.00034	9b6np45, 9b6np45.out	0.40645
	5.0	0.91149	0.00040	9b6-50, 9b6-50.out	1.31799	0.00030	9b6-5np, 9b6-5np.out	0.40650
6.25	4.0	0.80501	0.00036	9b625-4, 9b625-4.out	1.22874	0.00032	9b625np4, 9b625np4.out	0.42373
	4.5	0.82945	0.00041	9b625-45, 9b625-45.out	1.25650	0.00031	9b62np45, 9b62np45.out	0.42705
	5.0	0.84951	0.00039	9b625, 9b625.out	1.27729	0.00031	9b625np, 9b625np.out	0.42778
6.5	4.0	0.75267	0.00039	9b65-40, 9b65-40.out	1.18301	0.00033	9b65np4, 9b65np4.out	0.43034
	4.5	0.77531	0.00039	9b65-45, 9b65-45.out	1.20956	0.00031	9b65np45, 9b65np45.out	0.43425
	5.0	0.79396	0.00037	9b65-50, 9b65-50.out	1.23165	0.00036	9b65np5, 9b65np5.out	0.43769

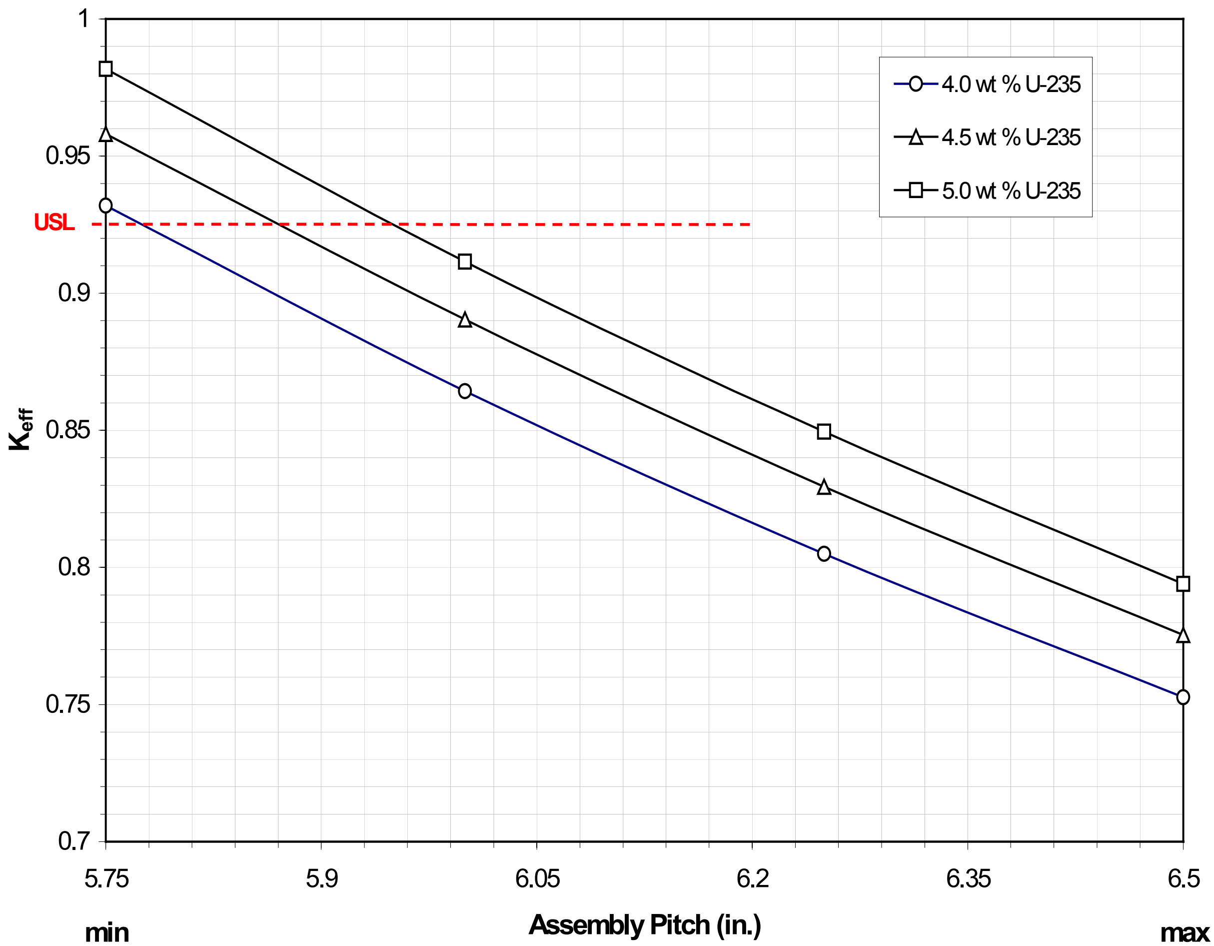

Figure 6.2-1 BWR Storage Rack Assembly Pitch versus k_{eff} for Various Enrichments

Table 6.2-2 displays k_{eff} as a function of varied moderator density between 0.0 to 1.0 g/cm^3 for 5.0 wt % enrichment and various storage rack assembly pitches. It can be seen that the reactivity of the loaded storage rack decreases with reduction in moderator density. Figure 6.2-2 shows k_{eff} as a function of moderator variations for 9.0, 10.0, and 11.0 inch assembly pitches with 5.0 wt % enrichment.

An additional calculation was performed utilizing an interior moderator density of 0.0 g/cm^3 with water (density of 1.0 g/cm^3) surrounding the SS vessel (MCNP files 9b6-0W and 9b6-0W.out). The result, k_{eff}=0.44988 with a standard deviation of 0.00017, shows when compared with Table 6.2-2 that a potential flooding outside the SS vessel in the DTF does not increase the reactivity in the storage rack.

Table 6.2-2 Moderator Density Variations at Various Assembly Pitches for 5.0 wt % Enrichment

Density (g/cm^3)	6.0 in. pitch			6.25 in. pitch			6.5 in. pitch		
	K_{eff}	St. Dev.	MCNP files [a]	K_{eff}	St. Dev.	MCNP files [b]	K_{eff}	St. Dev.	MCNP files [c]
1.0	0.91149	0.00040	9b6-50 9b6-50.out	0.84951	0.00039	9b625 9b625.out	0.79396	0.00037	9b65-50 9b65-50.out
0.98	0.90799	0.00040	9b6-98 9b6-98.out	0.84564	0.00042	9b625-98 9b625-98.out	0.79184	0.00035	9b65-98 9b65-98.out
0.95	0.90141	0.00038	9b6-95 9b6-95.out	0.83995	0.00036	9b625-95 9b625-95.out	0.78607	0.00038	9b65-95 9b65-95.out
0.5	0.76310	0.00035	9b6-05 9b6-05.out	0.72731	0.00037	9b625-05 9b625-05.out	0.69193	0.00033	9b65-05 9b65-05.out
0.3	0.66407	0.00034	9b6-03 9b6-03.out	0.64415	0.00033	9b625-03 9b625-03.out	0.62370	0.00031	9b65-03 9b65-03.out
0.1	0.55300	0.00022	9b6-01 9b6-01.out	0.54443	0.00024	9b625-01 9b625-01.out	0.53632	0.00023	9b65-01 9b65-01.out
0.08	0.54413	0.00025	9b6-008 9b6-008.out	0.53649	0.00024	9b625008 9b625008.out	0.52997	0.00021	9b65-008 9b65-008.out
0.05	0.53150	0.00020	9b6-005 9b6-005.out	0.52571	0.00020	9b625005 9b625005.out	0.52067	0.00020	9b65-005 9b65-005.out
0.03	0.52474	0.00020	9b6-003 9b6-003.out	0.52073	0.00019	9b625003 9b625003.out	0.51598	0.00022	9b65-003 9b65-003.out
0.01	0.50502	0.00017	9b6-001 9b6-001.out	0.50075	0.00018	9b625001 9b625001.out	0.49715	0.00017	9b65-001 9b65-001.out
0.005	0.49672	0.00017	9b60005 9b60005.out	0.49222	0.00015	9b620005 9b620005.out	0.48819	0.00015	9b650005 9b650005.out
0.0	0.48429	0.00015	9b6-0 9b6-0.out	0.47917	0.00014	9b625-0 9b625-0.out	0.47376	0.00016	9b65-0 9b65-0.out

[a] Files, except for b6-50 and b6-50.out, are located in directory BWR/6-PITCH
[b] Files, except for b65-50 and b65-50.out, are located in directory BWR/625-PITCH
[c] Files, except for b7-50 and b7-50.out, are located in directory BWR/65-PITCH

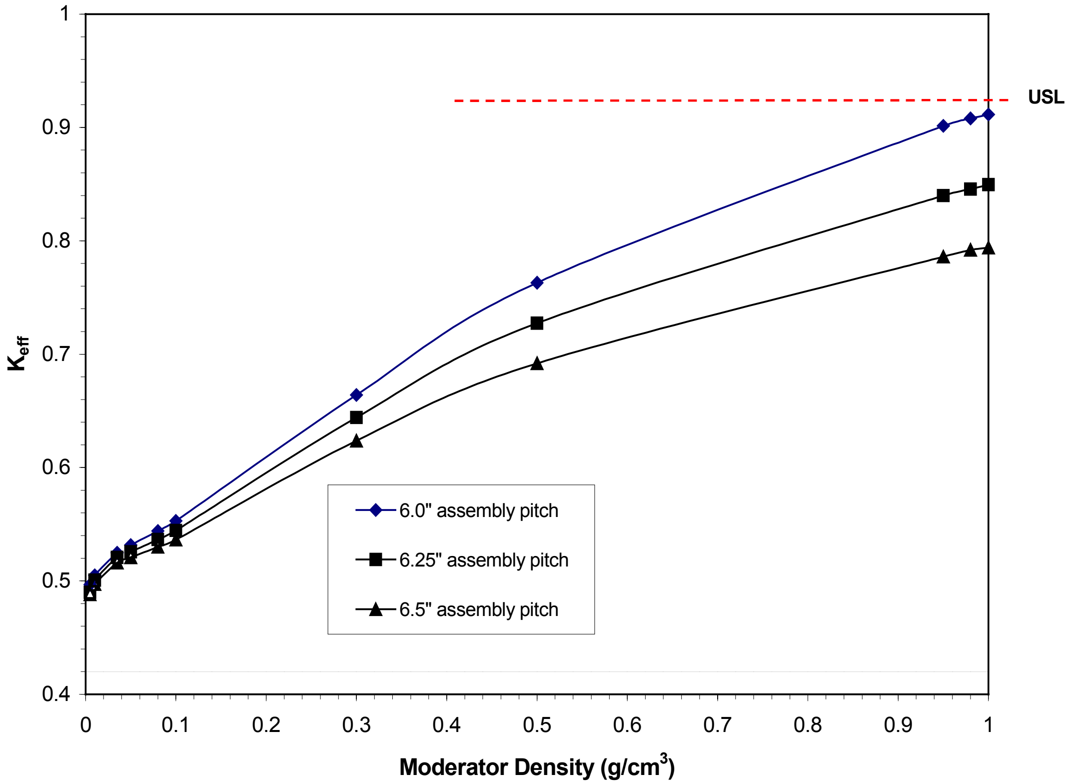

Figure 6.2-2 Moderator Density Variations versus k_{eff} for Various BWR Assembly Pitches

The BWR storage rack configuration for the RB (Section 5.1.4) was analyzed for various assembly pitches at 5.0 wt % enrichment. Table 6.2-3 displays the k_{eff} values and it can be seen that in order to meet the design criteria (i.e., k_{eff} of 0.95 including bias and uncertainties per Assumption 3.3), the RB storage rack must utilize a minimum pitch of 6.25 in. This pitch is slightly higher compared to the DTF storage configuration that only needs 6 in. (see Table 6.2-1).

Table 6.2-3 K_{eff} of the RB BWR Storage Configuration

Pitch (in.)	Enrichment (wt%)	K_{eff}	St. Dev.	MCNP files
5.75	5.0	1.01423	0.00039	9rb575, 9rb575.out
6.0	5.0	0.93981	0.00037	9rb6-5, 9rb6-5.out
6.25	5.0	0.87270	0.00040	9rb625, 9rb625.out
6.5	5.0	0.81264	0.00039	9rb65-5, 9rb65-5.out

The effects of potential moderator intrusion into the RB BWR storage area have been evaluated. Table 6.2-4 presents the k_{eff} values as a function of moderator height (1.0 g/cm^3 moderator density) for an assembly pitch of 6.25 inches and 5.0 wt % enrichment. It can be seen that moderator intrusion of the fuel storage rack will still promote a k_{eff} remaining within 0.95 including uncertainties and bias (Assumption 3.3).

Table 6.2-4 K_{eff} Values as a Function of Moderator Height

Moderator height (%)	K_{eff}	St. Dev.	MCNP files
0	0.63146	0.00016	0rb625n, 0rb625n.out
28	0.85647	0.00036	25rb625n, 25rb625n.out
50	0.86712	0.00037	50rb625n, 50rb625n.out
78	0.87099	0.00034	75rb625n, 75rb625n.out
88	0.87235	0.00035	88rb625n, 88rb625n.out
100	0.87243	0.00039	10rb625n, 10rb625n.out

6.3 CATEGORY 1 AND 2 EVENT SEQUENCES

Category 1 and 2 event sequences were evaluated as presented in Section 5.2.3 and were found to be within the criticality safety design limits.

6.4 CONCLUSIONS AND RECOMMENDATIONS

The DTF and RB facilities and processes have been evaluated for criticality safety for normal operations, Category 1 and 2 event sequences. The results presented in this document lead to the following conclusions and recommendations:

- Fixed neutron absorber is required in the storage racks to ensure adequate safety margin. In the analyzed configuration the fixed absorber reduces reactivity by a maximum of approximately 22 % for the PWR fuel and approximately 35 % for the BWR fuel.

- A storage rack pitch of 6.0 in. and 11.0 in. for BWR and PWR fuel assemblies, respectively (based on a standard fixed neutron absorber specifications) at 5.0 wt % enrichment will provide adequate criticality safety for both normal, off-normal and accident conditions (inclusive of Category 1 and 2 event sequences identified at date of this design calculation) for the DTF. A storage rack pitch of 6.25 in. is required for the BWR fuel assemblies in the RB. In addition, a storage rack pitch of 11.25 in. is required for the PWR fuel assemblies in the RB. It should be mentioned, however, that with inherent conservatism (e.g., uniform 5.0 wt % enrichment) built into the calculation, an 11 in. assembly pitch may be acceptable in the RB. Future work will need to be performed to quantify the conservatism.

- Reactivity of the loaded staging and storage racks decreases with reduction in moderator density.

- Maximum reactivity is reached when the fuel storage racks are fully flooded with water at full density (1.0 g/cm^3). Full flooding would require maximum fuel assembly pitch to meet the criticality design criteria. The maximum fuel assembly pitch for the fully flooded conditions is only slightly greater than the nominal physical spacing required between the fuel assemblies. Therefore, moderator intrusion would not impact the size of the DTF fuel staging area significantly.

- Category 1 and 2 event sequences potentially occurring in these facilities do not compromise criticality safety. It should be recognized that the event sequences analyzed in this design calculation are preliminary.

This design calculation uses a nominal k_{eff} value as a basis for determining the storage rack pitch requirements in conjunction with a fixed Boral panel specification for neutron poison. Although the nominal value provides the necessary margin for meeting the criterion of 0.95 in the *Project Design Criteria* Document (Minwalla 2003, Section 4.9.2.2), it is recommended that this margin be demonstrated to be satisfactory by performing the relevant benchmark calculations for code bias, and obtaining all pertinent uncertainties. As this design calculation provides the results in a parametric manner, the outputs are useful to reflect and accommodate possible design changes. However, the Nuclear Analysis group should be consulted for accurate interpretation of the outputs and effects on the design.

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8. ATTACHMENTS

This calculation document includes three attachments:

ATTACHMENT I	Listing of Computer Files (10 pages)
ATTACHMENT II	One Compact Disk Containing All Files Listed in Attachment I (1 of 1) (0 pages)
ATTACHMENT III	Sketches of DTF and RB moderator exclusion areas (8 pages)

ATTACHMENT I
LISTING OF COMPUTER FILES

This attachment lists the input and output file names for the MCNP and Excel calculations. All input and output are stored on an electronic medium (compact disc) in ASCII format as part of this attachment.

Date	Time	File Size	File Name
05/30/2003	11:05a	33,792	fuelcomp.xls
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05/06/2003	03:07p	2,953	PinCell/BW155
05/07/2003	03:04a	279,343	PinCell/BW155.out
04/17/2003	03:18p	3,018	PinCell/bw17
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07/10/2003	09:31a	2,980	PinCell/bwr14
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02/26/2004	09:05a	2,959	PinCell/bwr14D
02/26/2004	09:05a	278,496	PinCell/bwr14D.out
07/10/2003	09:26a	2,964	PinCell/bwr15
07/11/2003	01:48a	440,588	PinCell/bwr15.out
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05/16/2003	02:47p	279,185	PinCell/ce165.out
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05/06/2003	09:53a	2,999	PinCell/w14ofa5
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03/02/2004	11:33a	3,209	PinCell/w17o09D
03/02/2004	11:33a	278,307	PinCell/w17o09D.out
07/08/2003	08:50a	3,209	PinCell/w17o10
07/09/2003	03:12p	440,667	PinCell/w17o10.out
03/02/2004	11:33a	3,191	PinCell/w17o10D
03/02/2004	11:33a	197,425	PinCell/w17o10D.out
07/08/2003	08:52a	3,201	PinCell/w17o11
07/09/2003	01:25a	440,461	PinCell/w17o11.out
03/02/2004	11:33a	3,184	PinCell/w17o11D
03/02/2004	11:33a	278,101	PinCell/w17o11D.out
02/26/2004	09:06a	3,128	PinCell/w17o12
02/26/2004	09:06a	279,233	PinCell/w17o12.out
03/02/2004	11:33a	3,181	PinCell/w17o12D
03/02/2004	11:33a	278,101	PinCell/w17o12D.out
02/26/2004	09:06a	3,128	PinCell/w17o13
02/26/2004	09:06a	279,233	PinCell/w17o13.out
02/26/2004	09:05a	3,110	PinCell/w17o13D
02/26/2004	09:05a	278,306	PinCell/w17o13D.out
02/26/2004	09:06a	3,128	PinCell/w17o14
02/26/2004	09:06a	279,233	PinCell/w17o14.out
03/02/2004	11:33a	3,111	PinCell/w17o14D
03/02/2004	11:33a	278,100	PinCell/w17o14D.out
02/26/2004	09:06a	3,128	PinCell/w17o145
02/26/2004	09:06a	279,233	PinCell/w17o145.out
02/26/2004	09:06a	3,128	PinCell/w17o15
02/26/2004	09:06a	279,233	PinCell/w17o15.out
02/26/2004	09:06a	3,128	PinCell/w17o16
02/26/2004	09:06a	279,233	PinCell/w17o16.out
02/26/2004	09:06a	3,128	PinCell/w17o17
02/26/2004	09:06a	279,233	PinCell/w17o17.out
02/26/2004	09:06a	3,128	PinCell/w17o18
02/26/2004	09:06a	279,233	PinCell/w17o18.out

Date	Time	File Size	File Name
02/26/2004	09:06a	3,128	PinCell/w17o19
02/26/2004	09:06a	279,233	PinCell/w17o19.out
05/07/2003	07:00a	3,277	PinCell/w17ofa
05/07/2003	09:10a	279,280	PinCell/w17ofa.out
04/19/2003	08:31a	3,275	PinCell/w17ofa5
04/19/2003	12:03p	440,461	PinCell/w17ofa5.out
03/02/2004	11:33a	3,231	PinCell/w17ofa5D
03/02/2004	11:34a	278,101	PinCell/w17ofa5D.out
05/07/2003	06:56a	3,068	PinCell/w17std
05/07/2003	08:22a	279,280	PinCell/w17std.out
04/19/2003	08:26a	3,066	PinCell/w17std5
04/19/2003	10:34a	440,398	PinCell/w17std5.out
05/12/2003	01:48p	112,105	PWR/p10-40
05/12/2003	01:48p	651,268	PWR/p10-40.out
05/12/2003	01:48p	112,105	PWR/p10-45
05/12/2003	01:48p	651,183	PWR/p10-45.out
05/12/2003	01:48p	112,089	PWR/p10-4np
05/12/2003	01:48p	650,852	PWR/p10-4np.out
05/12/2003	01:48p	112,105	PWR/p10-50
05/12/2003	01:48p	651,389	PWR/p10-50.out
05/12/2003	01:48p	112,089	PWR/p10-5np
05/12/2003	01:49p	650,852	PWR/p10-5np.out
05/12/2003	01:49p	112,682	PWR/p105-40
05/12/2003	01:49p	651,494	PWR/p105-40.out
05/12/2003	01:49p	112,995	PWR/p105-45
05/12/2003	01:49p	651,306	PWR/p105-45.out
05/12/2003	01:49p	113,697	PWR/p105-50
05/12/2003	01:49p	652,705	PWR/p105-50.out
05/12/2003	01:49p	112,666	PWR/p105N4
05/12/2003	01:49p	651,176	PWR/p105N4.out
05/12/2003	01:49p	112,979	PWR/p105N45
05/12/2003	01:49p	651,109	PWR/p105N45.out
05/12/2003	01:49p	113,663	PWR/p105N5
05/12/2003	01:49p	652,070	PWR/p105N5.out
05/12/2003	01:49p	112,089	PWR/p10N45
05/12/2003	01:49p	650,767	PWR/p10N45.out
05/12/2003	01:49p	114,161	PWR/p11-40
05/12/2003	01:49p	653,718	PWR/p11-40.out
05/12/2003	01:49p	115,175	PWR/p11-45
05/12/2003	01:49p	650,324	PWR/p11-45.out
05/12/2003	01:49p	114,145	PWR/p11-4np
05/12/2003	01:49p	654,054	PWR/p11-4np.out
03/02/2004	11:03a	125,676	PWR/p11-5n
03/02/2004	11:03a	752,434	PWR/p11-5n.out

Date	Time	File Size	File Name
05/12/2003	01:49p	114,971	PWR/p11-5np
05/12/2003	01:49p	650,998	PWR/p11-5np.out
03/02/2004	11:03a	125,835	PWR/p11-5S
03/02/2004	11:03a	752,626	PWR/p11-5S.out
05/12/2003	01:49p	115,159	PWR/p11N45
05/12/2003	01:49p	649,921	PWR/p11N45.out
05/12/2003	01:49p	112,210	PWR/p9-40
05/12/2003	01:49p	647,640	PWR/p9-40.out
05/12/2003	01:49p	112,194	PWR/p9-40np
05/12/2003	01:49p	647,224	PWR/p9-40np.out
05/12/2003	01:49p	112,524	PWR/p9-45
05/12/2003	01:49p	651,028	PWR/p9-45.out
05/12/2003	01:49p	112,508	PWR/p9-45np
05/12/2003	01:49p	650,514	PWR/p9-45np.out
05/12/2003	01:49p	112,636	PWR/p9-50
05/12/2003	01:49p	651,216	PWR/p9-50.out
05/12/2003	01:49p	112,620	PWR/p9-50np
05/12/2003	01:49p	650,702	PWR/p9-50np.out
03/02/2004	11:11a	124,979	PWR/rb11-5w
03/02/2004	11:11a	750,787	PWR/rb11-5w.out
03/02/2004	11:11a	125,384	PWR/rb125-5
03/02/2004	11:11a	750,787	PWR/rb125-5.out
05/12/2003	01:49p	113,811	PWR/rb5-asm
05/12/2003	01:49p	647,119	PWR/rb5-asm.out
02/26/2004	09:05a	113,495	PWR/rb5asm2
02/26/2004	09:05a	654,131	PWR/rb5asm2.out
02/26/2004	09:05a	113,573	PWR/rb5asm3
02/26/2004	09:05a	653,928	PWR/rb5asm3.out
02/26/2004	09:05a	113,516	PWR/rb5asm4
02/26/2004	09:05a	654,249	PWR/rb5asm4.out
03/02/2004	11:11a	180,497	PWR/rb11-0n
03/02/2004	11:11a	1,106,417	PWR/rb11-0n.out
03/02/2004	11:11a	179,808	PWR/rb11-25n
03/02/2004	11:11a	959,155	PWR/rb11-25n.out
03/02/2004	11:11a	179,880	PWR/rb11-50n
03/02/2004	11:11a	958,169	PWR/rb11-50n.out
03/02/2004	11:11a	180,633	PWR/rb11-75n
03/02/2004	11:11a	961,261	PWR/rb11-75n.out
03/02/2004	11:11a	180,633	PWR/rb11-88n
03/02/2004	11:11a	961,055	PWR/rb11-88n.out
05/12/2003	01:49p	114,107	PWR/rb11-5
05/12/2003	01:49p	647,728	PWR/rb11-5.out
03/02/2004	11:15a	229,848	PWR/rb1125B2
03/02/2004	11:15a	1,141,822	PWR/rb1125B2.out

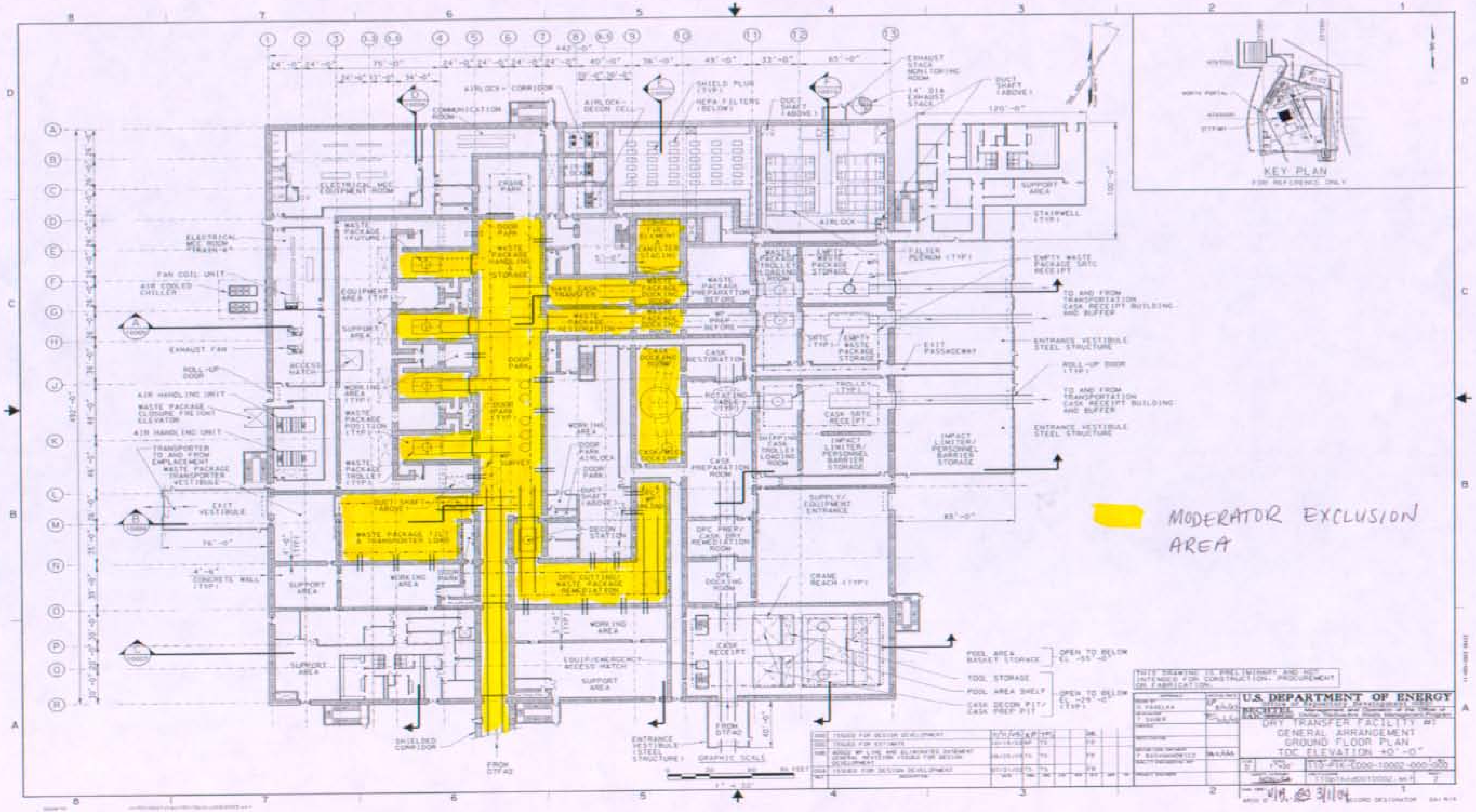
Date	Time	File Size	File Name
03/02/2004	02:05p	228,840	PWR/rb1125B
03/02/2004	02:05p	1,093,297	PWR/rb1125B.out
02/26/2004	09:06a	216,511	PWR/rb11H5
02/26/2004	09:06a	1,084,025	PWR/rb11H5.out
02/26/2004	09:06a	210,053	PWR/rb11H5a
02/26/2004	09:06a	1,078,524	PWR/rb11H5a.out
08/09/2003	09:46a	88,318	PWR/w14-5
08/09/2003	09:46a	532,942	PWR/w14-5.out
02/26/2004	09:14a	88,468	PWR/w14-5A
02/26/2004	09:14a	534,718	PWR/w14-5A.out
05/12/2003	01:48p	111,361	PWR/9-PITCH/pwr-0
05/12/2003	01:48p	652,294	PWR/9-PITCH/pwr-0.out
05/12/2003	01:48p	112,308	PWR/9-PITCH/pwr-001
05/12/2003	01:48p	699,432	PWR/9-PITCH/pwr-001.out
05/12/2003	01:48p	112,325	PWR/9-PITCH/pwr-005
05/12/2003	01:48p	652,741	PWR/9-PITCH/pwr-005.out
05/12/2003	01:48p	112,325	PWR/9-PITCH/pwr-008
05/12/2003	01:48p	652,539	PWR/9-PITCH/pwr-008.out
05/12/2003	01:48p	112,020	PWR/9-PITCH/pwr-01
05/12/2003	01:48p	652,539	PWR/9-PITCH/pwr-01.out
05/12/2003	01:48p	112,020	PWR/9-PITCH/pwr-03
05/12/2003	01:48p	652,539	PWR/9-PITCH/pwr-03.out
05/12/2003	01:48p	112,636	PWR/9-PITCH/pwr-05
05/12/2003	01:48p	650,196	PWR/9-PITCH/pwr-05.out
05/12/2003	01:48p	112,630	PWR/9-PITCH/pwr0005
05/12/2003	01:48p	652,539	PWR/9-PITCH/pwr0005.out
05/12/2003	01:48p	112,630	PWR/9-PITCH/pwr0035
05/12/2003	01:48p	652,539	PWR/9-PITCH/pwr0035.out
07/17/2003	02:04p	114,698	PWR/9-PITCH/p9-95
07/17/2003	02:04p	657,040	PWR/9-PITCH/p9-95.out
07/17/2003	02:04p	114,698	PWR/9-PITCH/p9-98
07/17/2003	02:04p	657,040	PWR/9-PITCH/p9-98.out
05/12/2003	01:48p	110,747	PWR/10-PITCH/pwr-0
05/12/2003	01:48p	652,144	PWR/10-PITCH/pwr-0.out
05/12/2003	01:48p	111,792	PWR/10-PITCH/pwr-001
05/12/2003	01:48p	652,793	PWR/10-PITCH/pwr-001.out
05/12/2003	01:48p	111,794	PWR/10-PITCH/pwr-005
05/12/2003	01:48p	652,591	PWR/10-PITCH/pwr-005.out
05/12/2003	01:48p	111,794	PWR/10-PITCH/pwr-008
05/12/2003	01:48p	652,591	PWR/10-PITCH/pwr-008.out
05/12/2003	01:48p	111,435	PWR/10-PITCH/pwr-01
05/12/2003	01:48p	652,793	PWR/10-PITCH/pwr-01.out
05/12/2003	01:48p	111,435	PWR/10-PITCH/pwr-03
05/12/2003	01:48p	651,773	PWR/10-PITCH/pwr-03.out

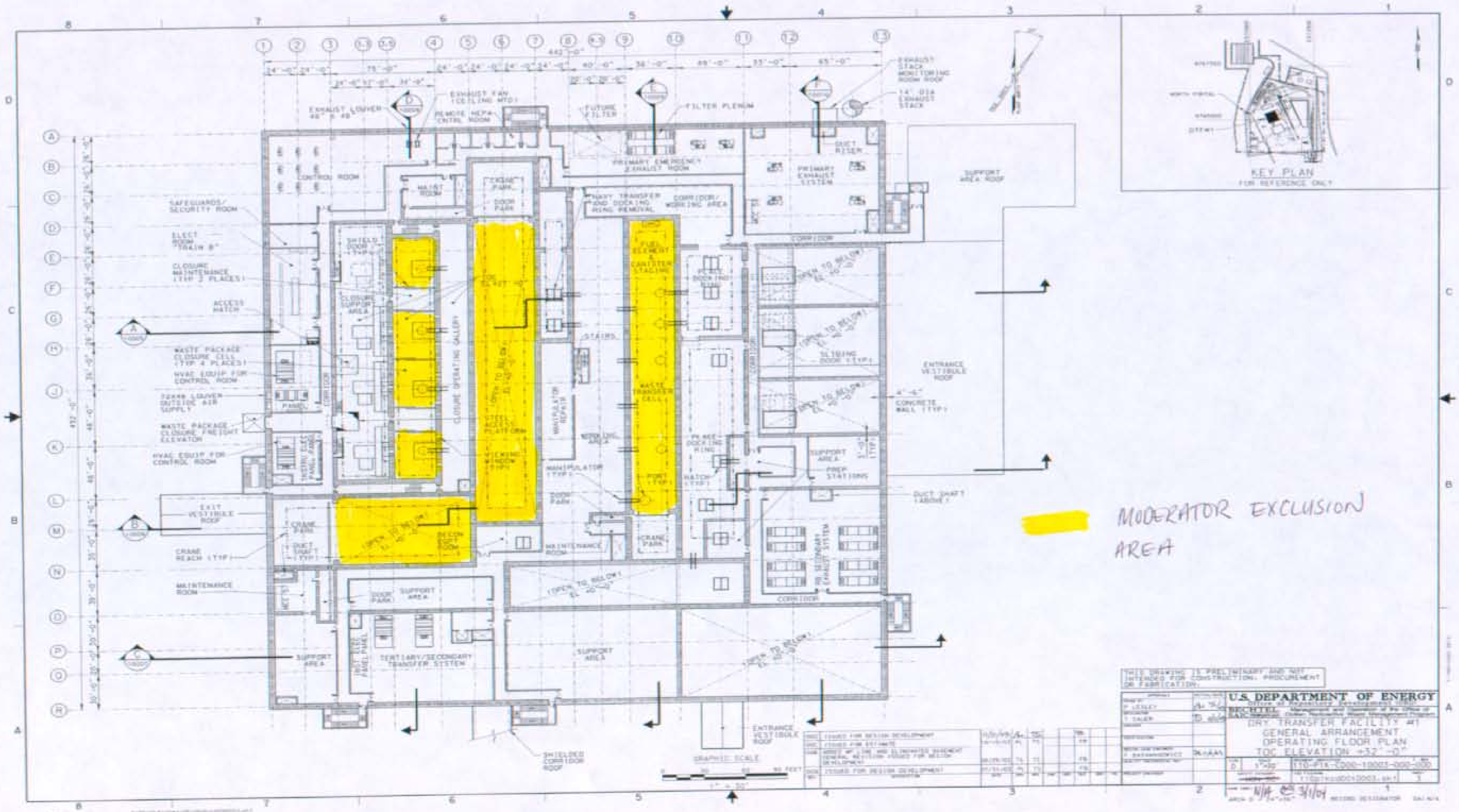
Date	Time	File Size	File Name
05/12/2003	01:48p	112,106	PWR/10-PITCH/pwr-05
05/12/2003	01:48p	651,268	PWR/10-PITCH/pwr-05.out
05/12/2003	01:48p	112,099	PWR/10-PITCH/pwr0005
05/12/2003	01:48p	652,793	PWR/10-PITCH/pwr0005.out
05/12/2003	01:48p	112,099	PWR/10-PITCH/pwr0035
05/12/2003	01:48p	652,591	PWR/10-PITCH/pwr0035.out
07/17/2003	02:04p	114,386	PWR/10-PITCH/p10-95
07/17/2003	02:04p	657,280	PWR/10-PITCH/p10-95.out
07/17/2003	02:04p	114,386	PWR/10-PITCH/p10-98
07/17/2003	02:04p	657,486	PWR/10-PITCH/p10-98.out
05/12/2003	01:48p	114,519	PWR/11-PITCH/pwr-0
05/12/2003	01:48p	652,290	PWR/11-PITCH/pwr-0.out
05/12/2003	01:48p	115,526	PWR/11-PITCH/pwr-001
05/12/2003	01:48p	652,939	PWR/11-PITCH/pwr-001.out
05/12/2003	01:48p	115,526	PWR/11-PITCH/pwr-005
05/12/2003	01:48p	652,939	PWR/11-PITCH/pwr-005.out
05/12/2003	01:48p	115,526	PWR/11-PITCH/pwr-008
05/12/2003	01:48p	652,737	PWR/11-PITCH/pwr-008.out
05/12/2003	01:48p	115,221	PWR/11-PITCH/pwr-01
05/12/2003	01:48p	652,939	PWR/11-PITCH/pwr-01.out
05/12/2003	01:48p	115,221	PWR/11-PITCH/pwr-03
05/12/2003	01:48p	652,737	PWR/11-PITCH/pwr-03.out
05/12/2003	01:48p	115,838	PWR/11-PITCH/pwr-05
05/30/2003	11:29p	649,225	PWR/11-PITCH/pwr-05.out
05/12/2003	01:48p	115,831	PWR/11-PITCH/pwr0005
05/12/2003	01:48p	652,939	PWR/11-PITCH/pwr0005.out
05/12/2003	01:48p	115,831	PWR/11-PITCH/pwr0035
05/12/2003	01:48p	652,737	PWR/11-PITCH/pwr0035.out
07/17/2003	02:05p	117,332	PWR/11-PITCH/p11-95
07/17/2003	02:05p	655,536	PWR/11-PITCH/p11-95.out
07/17/2003	02:05p	117,332	PWR/11-PITCH/p11-98
07/17/2003	02:05p	655,366	PWR/11-PITCH/p11-98.out
02/26/2004	08:58a	36,515	BWR/9b575
02/26/2004	08:58a	348,747	BWR/9b575.out
02/26/2004	08:58a	36,280	BWR/9b575-4
02/26/2004	08:58a	348,756	BWR/9b575-4.out
02/26/2004	08:58a	36,280	BWR/9b575-45
02/26/2004	08:58a	348,557	BWR/9b575-45.out
02/26/2004	08:59a	36,510	BWR/9b575np
02/26/2004	08:59a	348,143	BWR/9b575np.out
02/26/2004	08:58a	36,275	BWR/9b575np4
02/26/2004	08:58a	347,953	BWR/9b575np4.out
02/26/2004	08:58a	36,515	BWR/9b625
02/26/2004	08:58a	348,747	BWR/9b625.out

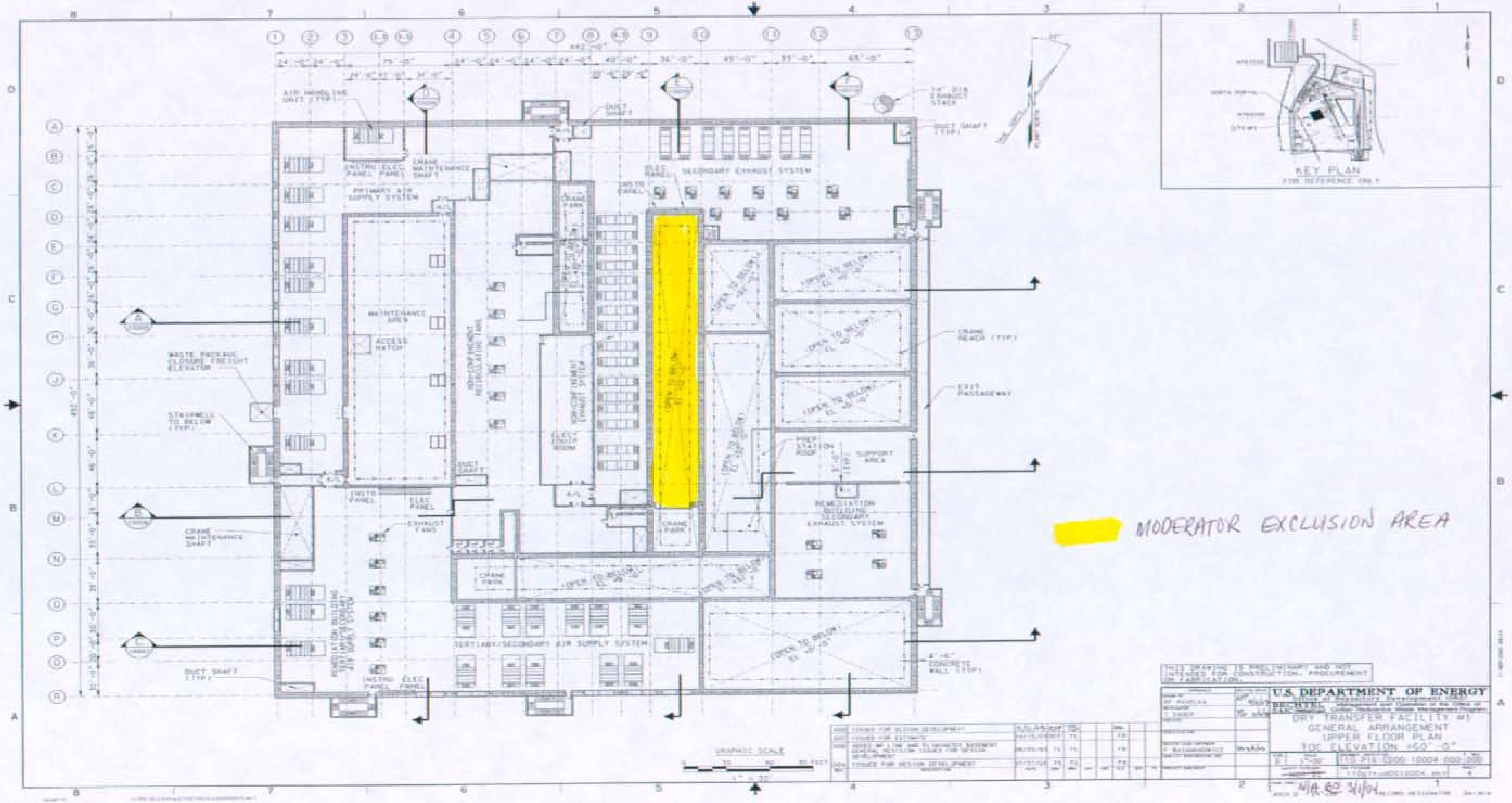
Date	Time	File Size	File Name
02/26/2004	08:58a	36,280	BWR/9b625-4
02/26/2004	08:58a	348,557	BWR/9b625-4.out
02/26/2004	08:58a	36,280	BWR/9b625-45
02/26/2004	08:58a	348,557	BWR/9b625-45.out
02/26/2004	08:59a	36,515	BWR/9b625np
02/26/2004	08:59a	348,143	BWR/9b625np.out
02/26/2004	08:58a	36,275	BWR/9b625np4
02/26/2004	08:58a	347,946	BWR/9b625np4.out
02/26/2004	08:58a	36,279	BWR/9b62np45
02/26/2004	08:58a	347,946	BWR/9b62np45.out
02/26/2004	08:58a	36,279	BWR/9b6-40
02/26/2004	08:58a	348,472	BWR/9b6-40.out
02/26/2004	08:58a	36,279	BWR/9b6-45
02/26/2004	08:58a	348,557	BWR/9b6-45.out
02/26/2004	08:58a	36,514	BWR/9b6-50
02/26/2004	08:58a	348,747	BWR/9b6-50.out
02/26/2004	08:59a	36,509	BWR/9b6-5np
02/26/2004	08:59a	348,143	BWR/9b6-5np.out
02/26/2004	08:58a	36,278	BWR/9b6np40
02/26/2004	08:58a	347,953	BWR/9b6np40.out
02/26/2004	08:58a	36,263	BWR/9b6np45
02/26/2004	08:58a	348,031	BWR/9b6np45.out
02/26/2004	08:58a	36,335	BWR/9b65-40
02/26/2004	08:58a	348,557	BWR/9b65-40.out
02/26/2004	08:58a	36,335	BWR/9b65-45
02/26/2004	08:58a	348,550	BWR/9b65-45.out
02/26/2004	08:58a	36,570	BWR/9b65-50
02/26/2004	08:58a	348,747	BWR/9b65-50.out
02/26/2004	08:58a	36,330	BWR/9b65np4
02/26/2004	08:58a	347,953	BWR/9b65np4.out
02/26/2004	08:58a	36,334	BWR/9b65np45
02/26/2004	08:58a	347,953	BWR/9b65np45.out
02/26/2004	08:59a	36,574	BWR/9b65np5
02/26/2004	08:59a	348,143	BWR/9b65np5.out
02/26/2004	09:02a	35,864	BWR/9rb575
02/26/2004	09:02a	346,361	BWR/9rb575.out
02/26/2004	09:02a	35,863	BWR/9rb6-5
02/26/2004	09:02a	346,528	BWR/9rb6-5.out
02/26/2004	09:02a	35,622	BWR/9rb625
02/26/2004	09:02a	346,544	BWR/9rb625.out
02/26/2004	09:02a	39,576	BWR/9rb65-5
02/26/2004	09:02a	346,449	BWR/9rb65-5.out
03/02/2004	11:26a	53,117	BWR/0rb625n
03/02/2004	11:26a	433,573	BWR/0rb625n.out

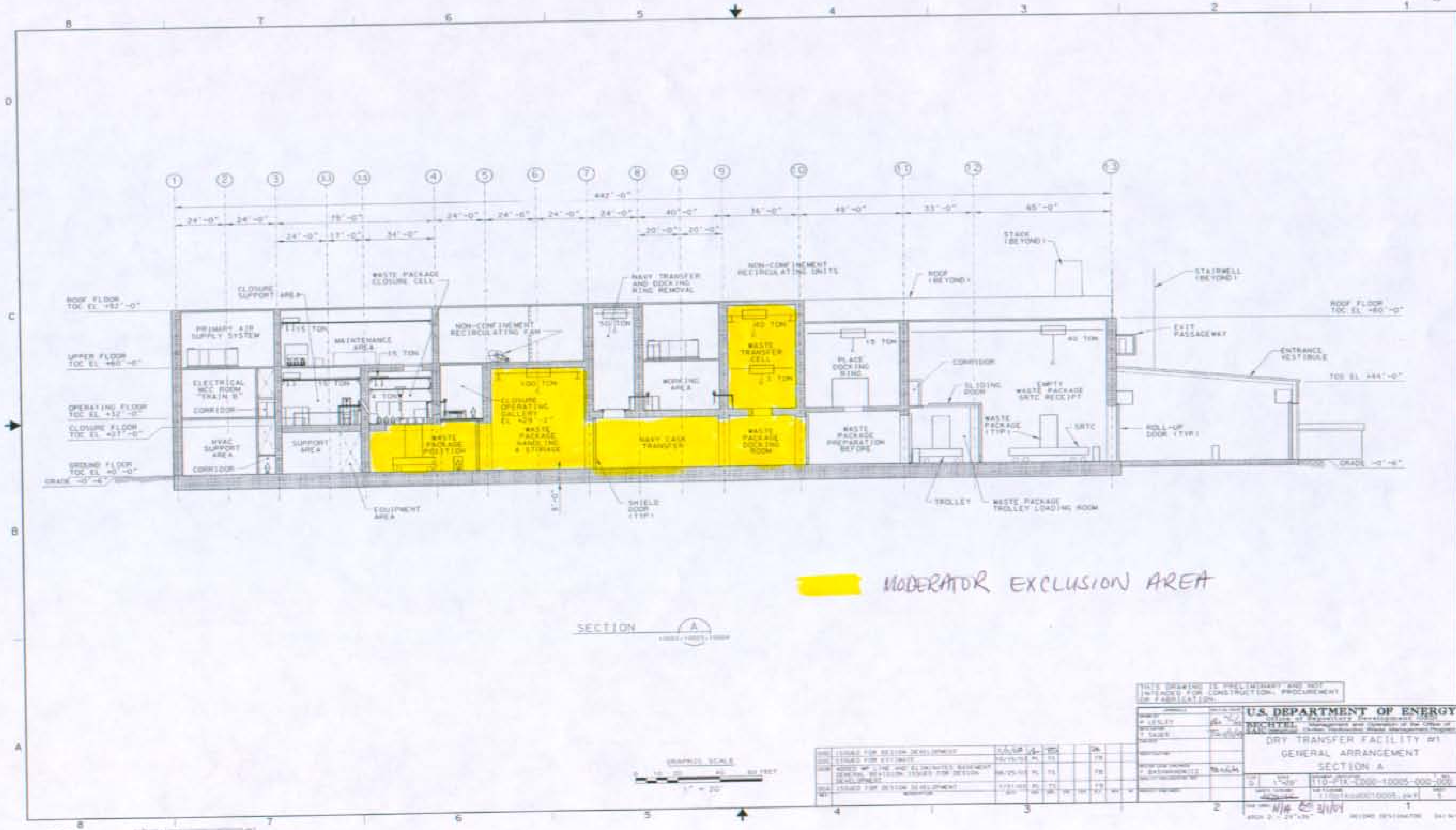
Date	Time	File Size	File Name
03/02/2004	11:26a	53,201	BWR/10rb625n
03/02/2004	11:26a	433,478	BWR/10rb625n.out
03/02/2004	11:26a	53,132	BWR/25rb625n
03/02/2004	11:26a	423,477	BWR/25rb625n.out
03/02/2004	11:26a	53,276	BWR/50rb625n
03/02/2004	11:26a	423,369	BWR/50rb625n.out
03/02/2004	11:26a	53,211	BWR/75rb625n
03/02/2004	11:26a	423,274	BWR/75rb625n.out
03/02/2004	11:26a	53,205	BWR/88rb625n
03/02/2004	11:26a	423,274	BWR/88rb625n.out
07/17/2003	02:01p	37,504	BWR/ge7x7
07/17/2003	02:01p	348,266	BWR/ge7x7.out
07/17/2003	02:01p	43,602	BWR/ge8x8
07/17/2003	02:01p	368,727	BWR/ge8x8.out
03/02/2004	03:43p	37,015	BWR/9b6S5-1
03/02/2004	03:43p	350,517	BWR/9b6S5-1.out
02/26/2004	08:58a	36,250	BWR/6-PITCH/9b6-0
02/26/2004	08:58a	348,499	BWR/6-PITCH/9b6-0.out
02/26/2004	08:58a	36,579	BWR/6-PITCH/9b6-001
02/26/2004	08:58a	348,747	BWR/6-PITCH/9b6-001.out
02/26/2004	08:59a	36,644	BWR/6-PITCH/9b60005
02/26/2004	08:59a	348,747	BWR/6-PITCH/9b60005.out
02/26/2004	08:58a	36,709	BWR/6-PITCH/9b6-003
02/26/2004	08:58a	348,747	BWR/6-PITCH/9b6-003.out
02/26/2004	08:58a	36,644	BWR/6-PITCH/9b6-005
02/26/2004	08:58a	348,953	BWR/6-PITCH/9b6-005.out
02/26/2004	08:58a	36,709	BWR/6-PITCH/9b6-008
02/26/2004	08:58a	348,747	BWR/6-PITCH/9b6-008.out
02/26/2004	08:58a	36,644	BWR/6-PITCH/9b6-01
02/26/2004	08:58a	348,747	BWR/6-PITCH/9b6-01.out
02/26/2004	08:58a	36,579	BWR/6-PITCH/9b6-03
02/26/2004	08:59a	348,747	BWR/6-PITCH/9b6-03.out
02/26/2004	08:59a	36,579	BWR/6-PITCH/9b6-05
02/26/2004	08:59a	348,747	BWR/6-PITCH/9b6-05.out
02/26/2004	08:59a	36,644	BWR/6-PITCH/9b6-95
02/26/2004	08:59a	348,747	BWR/6-PITCH/9b6-95.out
02/26/2004	08:59a	36,579	BWR/6-PITCH/9b6-98
02/26/2004	08:59a	348,747	BWR/6-PITCH/9b6-98.out
02/26/2004	08:58a	36,306	BWR/65-PITCH/9b65-0
02/26/2004	08:58a	348,293	BWR/65-PITCH/9b65-0.out
02/26/2004	08:58a	36,700	BWR/65-PITCH/9b650005
02/26/2004	08:58a	348,747	BWR/65-PITCH/9b650005.out
02/26/2004	08:58a	36,635	BWR/65-PITCH/9b65-001
02/26/2004	08:58a	348,747	BWR/65-PITCH/9b65-001.out

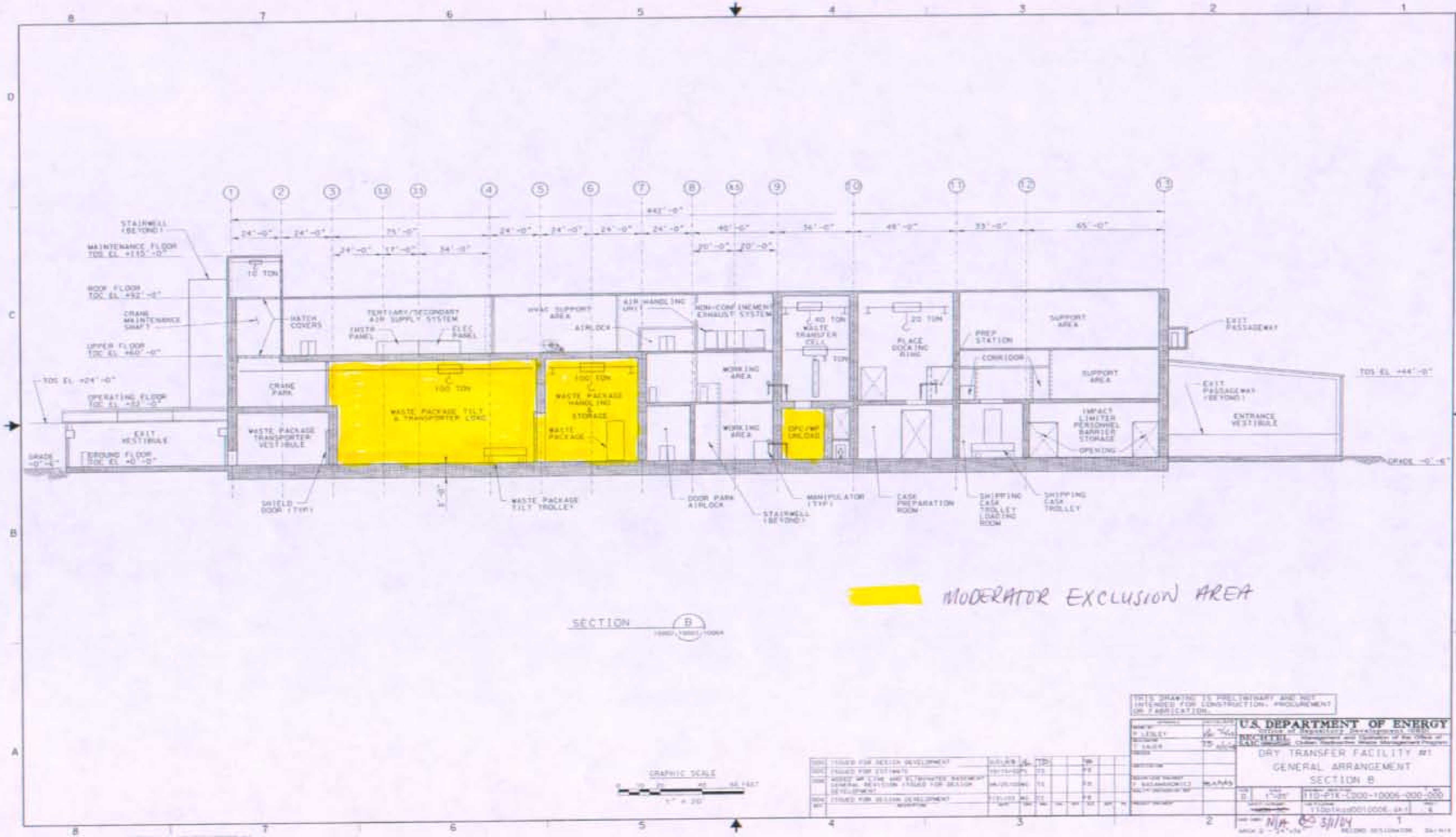
Date	Time	File Size	File Name
02/26/2004	08:58a	36,765	BWR/65-PITCH/9b65-003
02/26/2004	08:58a	348,747	BWR/65-PITCH/9b65-003.out
02/26/2004	08:58a	36,700	BWR/65-PITCH/9b65-005
02/26/2004	08:58a	348,747	BWR/65-PITCH/9b65-005.out
02/26/2004	08:58a	36,700	BWR/65-PITCH/9b65-008
02/26/2004	08:58a	348,747	BWR/65-PITCH/9b65-008.out
02/26/2004	08:58a	36,635	BWR/65-PITCH/9b65-01
02/26/2004	08:58a	348,747	BWR/65-PITCH/9b65-01.out
02/26/2004	08:58a	36,635	BWR/65-PITCH/9b65-03
02/26/2004	08:58a	348,953	BWR/65-PITCH/9b65-03.out
02/26/2004	08:58a	36,635	BWR/65-PITCH/9b65-05
02/26/2004	08:58a	348,731	BWR/65-PITCH/9b65-05.out
02/26/2004	08:58a	36,700	BWR/65-PITCH/9b65-95
02/26/2004	08:58a	348,747	BWR/65-PITCH/9b65-95.out
02/26/2004	08:58a	36,635	BWR/65-PITCH/9b65-98
02/26/2004	08:58a	348,747	BWR/65-PITCH/9b65-98.out
02/26/2004	08:58a	36,319	BWR/625-PITCH/9b625-0
02/26/2004	08:58a	348,293	BWR/625-PITCH/9b625-0.out
02/26/2004	08:58a	36,708	BWR/625-PITCH/9b625-01
02/26/2004	08:58a	348,953	BWR/625-PITCH/9b625-01.out
02/26/2004	08:58a	36,643	BWR/625-PITCH/9b625-03
02/26/2004	08:58a	348,747	BWR/625-PITCH/9b625-03.out
02/26/2004	08:58a	36,643 9	BWR/625-PITCH/b625-05
02/26/2004	08:58a	348,953	BWR/625-PITCH/9b625-05.out
02/26/2004	08:58a	36,708	BWR/625-PITCH/9b625-95
02/26/2004	08:58a	348,747	BWR/625-PITCH/9b625-95.out
02/26/2004	08:58a	36,708	BWR/625-PITCH/9b625-98
02/26/2004	08:58a	348,747	BWR/625-PITCH/9b625-98.out
02/26/2004	08:58a	36,708	BWR/625-PITCH/9b625001
02/26/2004	08:58a	348,953	BWR/625-PITCH/9b625001.out
02/26/2004	08:58a	36,773	BWR/625-PITCH/9b625003
02/26/2004	08:58a	348,953	BWR/625-PITCH/9b625003.out
02/26/2004	08:58a	36,708	BWR/625-PITCH/9b625005
02/26/2004	08:58a	348,953	BWR/625-PITCH/9b625005.out
02/26/2004	08:58a	36,708	BWR/625-PITCH/9b625008
02/26/2004	08:58a	348,747	BWR/625-PITCH/9b625008.out
02/26/2004	08:58a	36,713	BWR/625-PITCH/9b620005
02/26/2004	08:58a	149,719	BWR/625-PITCH/9b620005.out

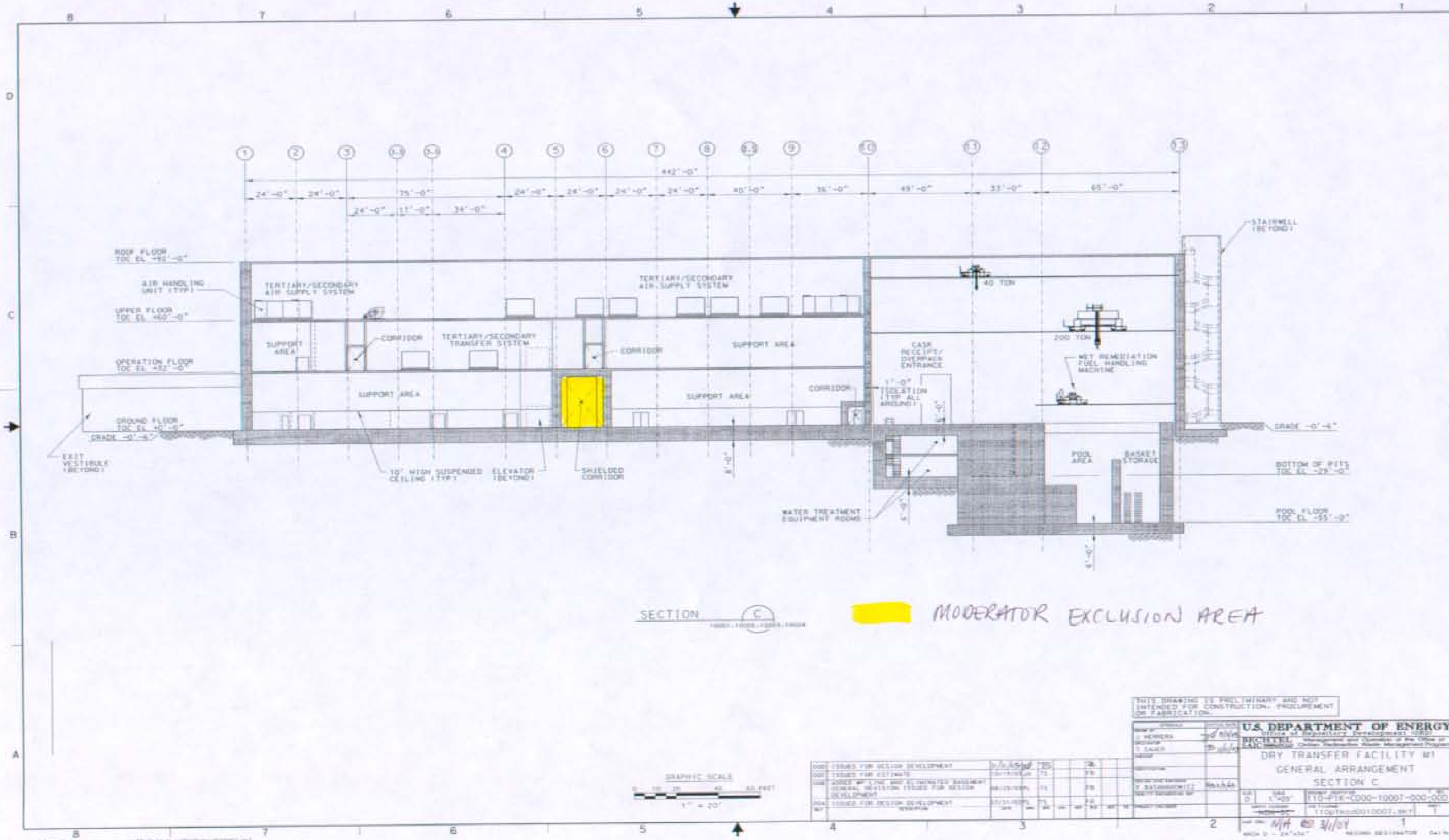

MODERATOR EXCLUSION AREA
KEY PLAN
FOR REFERENCE ONLY
THIS DRAWING IS PRELIMINARY AND NOT INTENDED FOR CONSTRUCTION, PROCUREMENT OR FABRICATION
U.S. DEPARTMENT OF ENERGY
BECHTEL SAIC
DRY TRANSFER FACILITY #1
GENERAL ARRANGEMENT
GROUND FLOOR PLAN
TOC ELEVATION +0'-0"
110-P1K-CD00-10002-000-00D
GRAPHIC SCALE
WASTE PACKAGE TILT & TRANSPORTER LOAD
DPC CUTTING/ WASTE PACKAGE REMEDIATION
CASK RECEIPT
SHIELDED CORRIDOR
FROM DTF#2
SUPPORT AREA
WORKING AREA
ELECTRICAL MEC EQUIPMENT ROOM
EXHAUST FAN
AIR HANDLING UNIT
EMPTY WASTE PACKAGE SRTC RECEIPT
TO AND FROM TRANSPORTATION CASK RECEIPT BUILDING AND BUFFER
ENTRANCE VESTIBULE STEEL STRUCTURE
ROLL-UP DOOR (TYP)
EXIT PASSAGEWAY
CRANE REACH (TYP)
POOL AREA BASKET STORAGE
TOOL STORAGE
POOL AREA SHELF
OPEN TO BELOW
CASK DECON PIT/ CASK PREP PIT
SUPPLY/ EQUIPMENT ENTRANCE
IMPACT LIMITER/ PERSONNEL BARRIER STORAGE
CASK PREPARATION ROOM
DPC DOCKING ROOM
DECON STATION
WORKING AREA
ENTRANCE VESTIBULE (STEEL STRUCTURE)
SUPPORT AREA
EXIT VESTIBULE
CONCRETE WALL (TYP)
AIRLOCK
STAIRWELL (TYP)
SUPPORT AREA
CRANE PARK
EXHAUST STACK MONITORING ROOM
DUCT SHAFT (ABOVE)
SHIELD PLUG (TYP)
HEPA FILTERS (BELOW)
AIRLOCK-CORRIDOR
COMMUNICATION ROOM
FAN COIL UNIT
AIR COOLED CHILLER
ACCESS HATCH
DOOR PARK


MODERATOR EXCLUSION AREA
KEY PLAN
U.S. DEPARTMENT OF ENERGY
DRY TRANSFER FACILITY #1
GENERAL ARRANGEMENT
OPERATING FLOOR PLAN


MODERATOR EXCLUSION AREA
U.S. DEPARTMENT OF ENERGY
BECHTEL
DRY TRANSFER FACILITY #1
GENERAL ARRANGEMENT
UPPER FLOOR PLAN
TOC ELEVATION +60'-0"
KEY PLAN


MODERATOR EXCLUSION AREA
SECTION A
U.S. DEPARTMENT OF ENERGY
BECHTEL
DRY TRANSFER FACILITY #1
GENERAL ARRANGEMENT
SECTION A


STAIRWELL (BEYOND)
MAINTENANCE FLOOR
ROOF FLOOR
CRANE MAINTENANCE SHAFT
UPPER FLOOR
OPERATING FLOOR
GROUND FLOOR
EXIT VESTIBULE
WASTE PACKAGE TRANSPORTER VESTIBULE
CRANE PARK
HATCH COVERS
TERTIARY/SECONDARY AIR SUPPLY SYSTEM
INSTR PANEL
ELEC PANEL
HVAC SUPPORT AREA
AIRLOCK
AIR HANDLING UNIT
NON-CONFINEMENT EXHAUST SYSTEM
100 TON
WASTE PACKAGE TILT & TRANSPORTER LOAD
WASTE PACKAGE HANDLING & STORAGE
WASTE PACKAGE
WORKING AREA
DPC/WP UNLOAD
40 TON
WASTE TRANSFER CELL
20 TON
PLACE DOCKING RING
PREP STATION
CORRIDOR
SUPPORT AREA
IMPACT LIMITER PERSONNEL BARRIER STORAGE
OPENING
EXIT PASSAGEWAY
EXIT PASSAGEWAY (BEYOND)
ENTRANCE VESTIBULE
SHIELD DOOR (TYP)
WASTE PACKAGE TILT TROLLEY
DOOR PARK AIRLOCK
STAIRWELL (BEYOND)
MANIPULATOR (TYP)
CASK PREPARATION ROOM
SHIPPING CASK TROLLEY LOADING ROOM
SHIPPING CASK TROLLEY
MODERATOR EXCLUSION AREA
SECTION B
GRAPHIC SCALE
THIS DRAWING IS PRELIMINARY AND NOT INTENDED FOR CONSTRUCTION, PROCUREMENT OR FABRICATION.
U.S. DEPARTMENT OF ENERGY
BECHTEL
DRY TRANSFER FACILITY #1
GENERAL ARRANGEMENT
SECTION B
110-P1K-CD00-10006-000-00D
N/A 3/1/04


ROOF FLOOR
TOC EL +92'-0"
AIR HANDLING
UNIT (TYP)
UPPER FLOOR
TOC EL +60'-0"
OPERATION FLOOR
TOC EL +32'-0"
GROUND FLOOR
TOC EL +0'-0"
GRADE -0'-6"
EXIT
VESTIBULE
(BEYOND)
TERTIARY/SECONDARY
AIR SUPPLY SYSTEM
SUPPORT
AREA
CORRIDOR
TERTIARY/SECONDARY
TRANSFER SYSTEM
SUPPORT AREA
CORRIDOR
10' HIGH SUSPENDED
CEILING (TYP)
ELEVATOR
(BEYOND)
SHIELDED
CORRIDOR
WATER TREATMENT
EQUIPMENT ROOMS
CASK
RECEIPT/
OVERPACK
ENTRANCE
1'-0"
ISOLATION
(TYP ALL
AROUND)
40 TON
200 TON
WET REMEDIATION
FUEL HANDLING
MACHINE
POOL
AREA
BASKET
STORAGE
STAIRWELL
(BEYOND)
GRADE -0'-6"
BOTTOM OF PITS
TOC EL -29'-0"
POOL FLOOR
TOC EL -55'-0"
442'-0"
SECTION C
MODERATOR EXCLUSION AREA
GRAPHIC SCALE
1" = 20'
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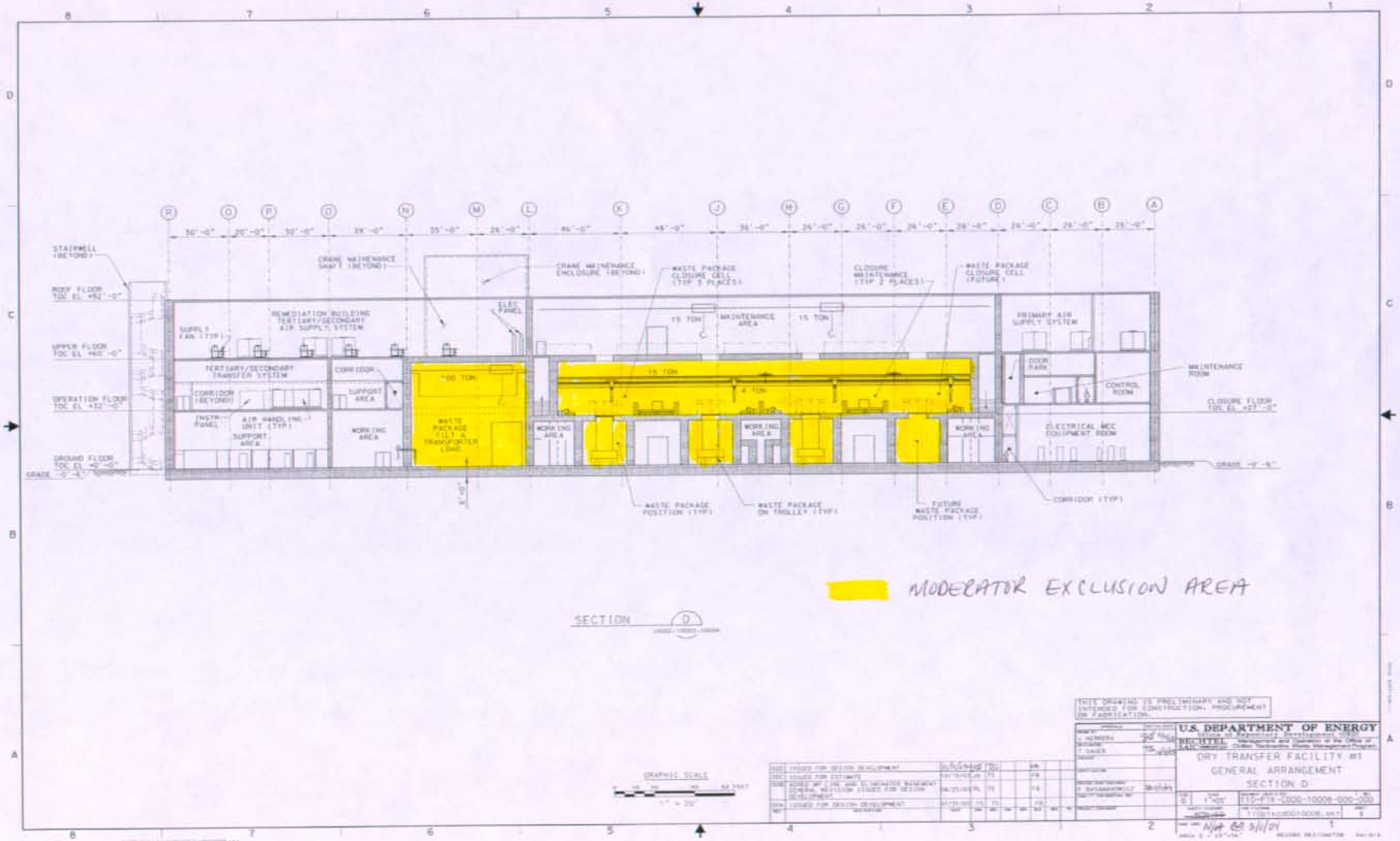
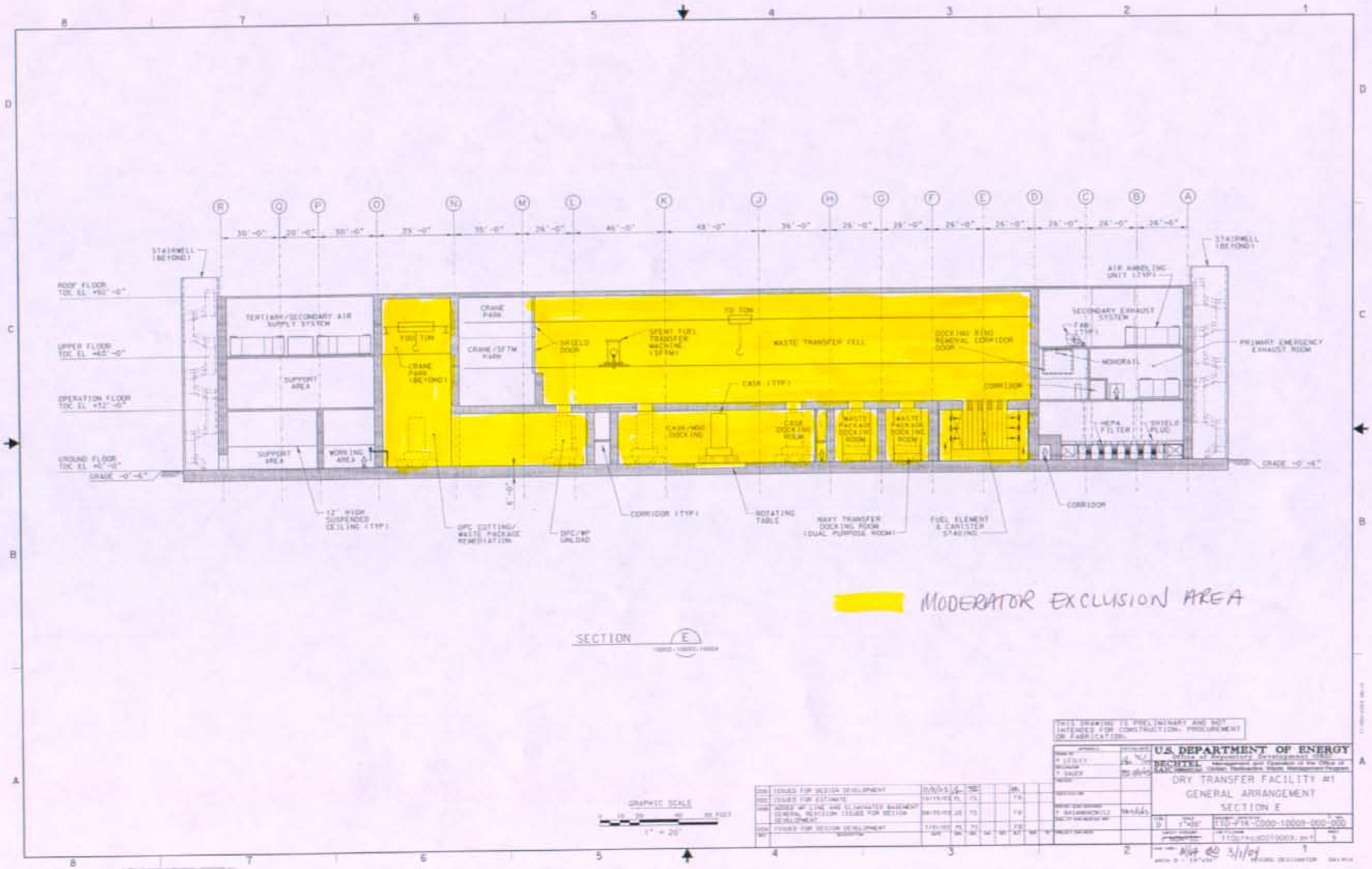
OR FABRICATION.
U.S. DEPARTMENT OF ENERGY
BECHTEL
DRY TRANSFER FACILITY #1
GENERAL ARRANGEMENT
SECTION C
110-P1K-C000-10007-000-00D


MODERATOR EXCLUSION AREA
SECTION D
U.S. DEPARTMENT OF ENERGY
DRY TRANSFER FACILITY #1
GENERAL ARRANGEMENT
SECTION D
THIS DRAWING IS PRELIMINARY AND NOT INTENDED FOR CONSTRUCTION, PROCUREMENT OR FABRICATION.
WASTE PACKAGE POSITION (TYP)
WASTE PACKAGE ON TROLLEY (TYP)
FUTURE WASTE PACKAGE POSITION (TYP)
CORRIDOR (TYP)
MAINTENANCE ROOM
CONTROL ROOM
ELECTRICAL MCC EQUIPMENT ROOM
PRIMARY AIR SUPPLY SYSTEM
WORKING AREA
15 TON
MAINTENANCE AREA
CLOSURE FLOOR
GRADE
STAIRWELL (BEYOND)
ROOF FLOOR
UPPER FLOOR
OPERATION FLOOR
GROUND FLOOR
CORRIDOR
SUPPORT AREA


MODERATOR EXCLUSION AREA
SECTION E
THIS DRAWING IS PRELIMINARY AND NOT INTENDED FOR CONSTRUCTION, PROCUREMENT OR FABRICATION
U.S. DEPARTMENT OF ENERGY
BECHTEL
DRY TRANSFER FACILITY #1
GENERAL ARRANGEMENT
SECTION E